RESEARCH PAPER NUMBER FORTY

CEMENT DISPERSION AND CONCRETE FLOORS

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FOREWORD

DURING some thirty years the Master Builders Company has devoted its research to the investigation of various problems in connection with concrete and especially concrete floors. Over this period there have been many new developments in materials and methods which have been applied to the improvement of cement floor construction.

The earliest development was that of the metallic aggregate floor which has been gradually improved from the time of its original conception, although not basically altered. More recently the application of the principle of dispersion to portland cement has effected radical improvements in the quality and economy of concrete. This principle has been successfully applied to cement floors, plain and colored, both with and without metallic aggregates.

It is the purpose of this paper to present to the industry the conclusions based on this study in a way which will explain just how cement dispersion and metallic aggregates, separately and combined, produce their results. In this manner the reasons for the recommendations made for cement floors for different purposes will be apparent, and selection of the proper materials and methods will be facilitated.

ABSTRACT

This paper discusses the problems involved in the construction of cement floors. The manner in which metallic aggregates function to solve these problems is described as is the mechanism whereby cement dispersion improves the efficiency of portland cement and the properties of concrete.

The application of metallic aggregates with a cement dispersing agent to cement floors is discussed with their effects on the properties of the resultant floor. The economic relations of different quantities of metallic aggregate and methods of construction are considered. Attention is also given to cement floors without metallic aggregates for certain purposes and it is shown that here also the principle of dispersion finds a place.

Colored cement floors have always presented a difficult problem. It is found that the most satisfactory solution seems to be the "dust coat" or "shake" method employing a shake composed of suitable pigment, metallic aggregate, cement dispersing agent, and cement in the proper proportions.

The question of liquid after-treatments is briefly considered. Where the original floor installation was properly made with suitable materials such after-treatments do not have any beneficial effect.

In five appendices certain special subjects, spark hazards, corrosive conditions, curing methods, colored floor finishes, and non-slip surfaces are treated.

CEMENT DISPERSION AND CONCRETE FLOORS

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CEMENT DISPERSION AND CONCRETE FLOORS

INTRODUCTION

CONCRETE when used for floors does not differ essentially from concrete for any other purpose but certain special qualities are required. First, the concrete mix must be capable of sustaining a considerable amount of finishing without deleterious effect in order to produce a smooth surface. Second, the floor must be resistant to impact and abrasion. It has been said that "the serviceability and even the life of a building depends primarily on its floors[1]" because they are the part subject to the greatest wear. In certain special cases other properties such as resistance to corrosion are required.

The first requisite of the finished floor is resistance to abrasion and it may be well to inquire how this can be produced. This property is the resultant of a number of other properties, notably strength, smoothness, and malleability. The wear on a concrete floor may be broken down into two factors, simple frictional abrasion and impact which is usually discussed as abrasion but is not abrasion at all.

Frictional abrasion, for a given type of floor such as concrete, is essentially a function of smoothness. It, therefore, depends on the ability to finish the floor properly, that is, the workability of the mix. It is also affected to a certain extent by the nature of the materials in the mix and the texture of the surface.

Most floors break down due to impact. No floor is an absolutely plane surface nor are the wheels which pass over it. Foot traffic obviously involves more or less impact. On most floors more or less hard and sometimes pointed objects are dropped either regularly or on occasion. Where truck wheels are involved there is a drop when the wheel passes over an inequality or irregularity of the surface. The effects of these forces are to break down the mortar, to chip out the aggregate and to shatter brittle aggregate. It will be evident that as this process continues the irregularities in the surface are aggravated so that greater impact forces are created and the deterioration of the floor proceeds at a rapidly increasing rate.

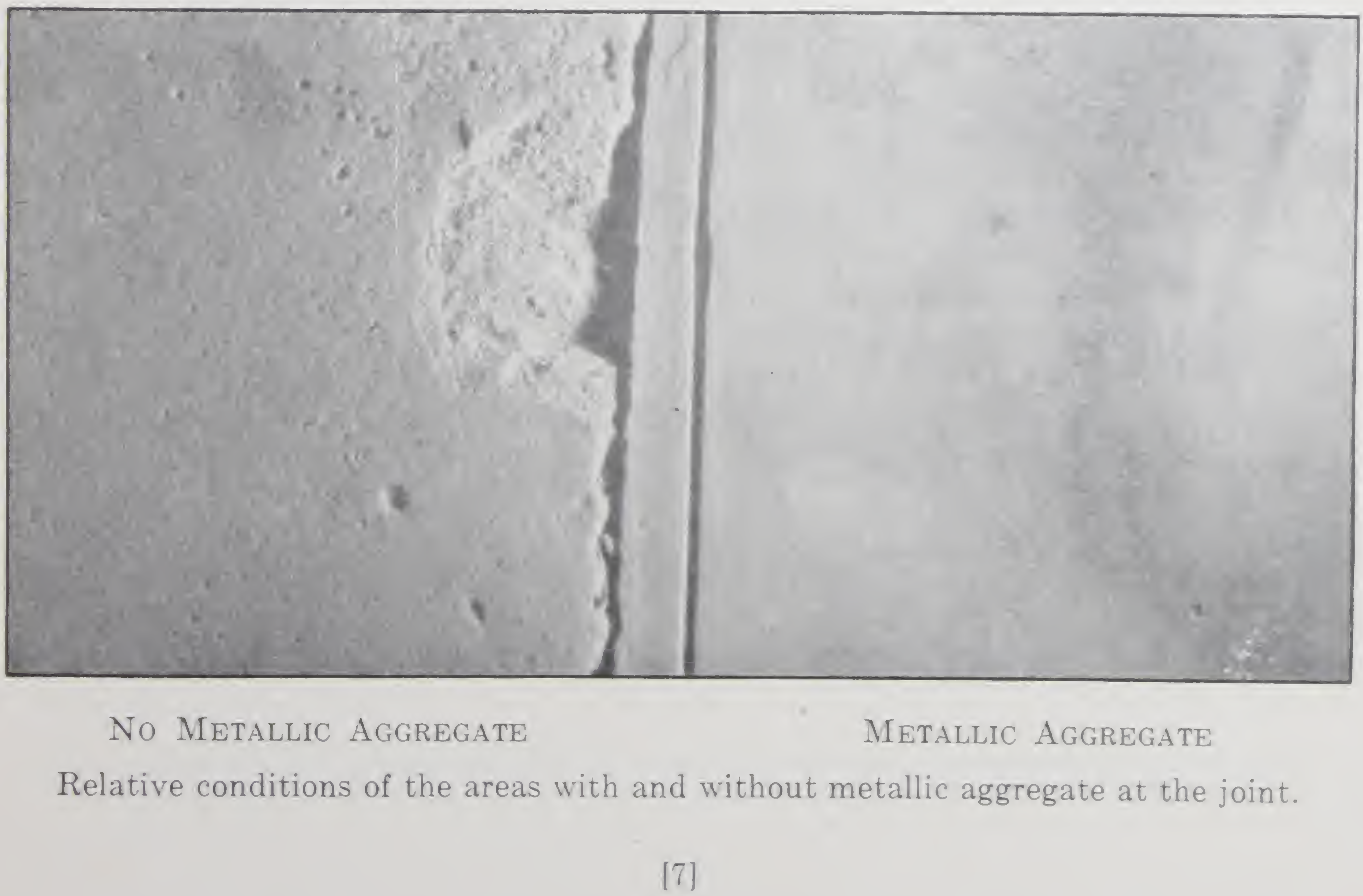
METALLIC AGGREGATES

A remarkably simple and effective means of solving this problem was discovered some thirty years ago. This was to replace the brittle stone aggregate in the surface of the floor with a metallic aggregate which was somewhat malleable. The effect of this was that impact tended to flatten instead of shatter the aggregates. This is well illustrated by the behavior of a diamond and a tenpenny nail on a railroad track upon passage of a locomotive. Although the diamond is the hardest of aggregates it is completely shattered and disappears from the track whereas the nail is flattened but remains adhering to the track and in substantially the same general shape as it had originally. Similarly the metallic aggregate in the floor surface is flattened under traffic tending to close up the pores, even out the irregularities and produce a floor surface which is worn away only very slowly. The metallic aggregate probably offers less frictional resistance. It has been amply demonstrated over a period of years that the use of metallic aggregates will increase the life of the floor many times. (Figs. I and II.)

[1]Portland Cement Association.

Fig. I

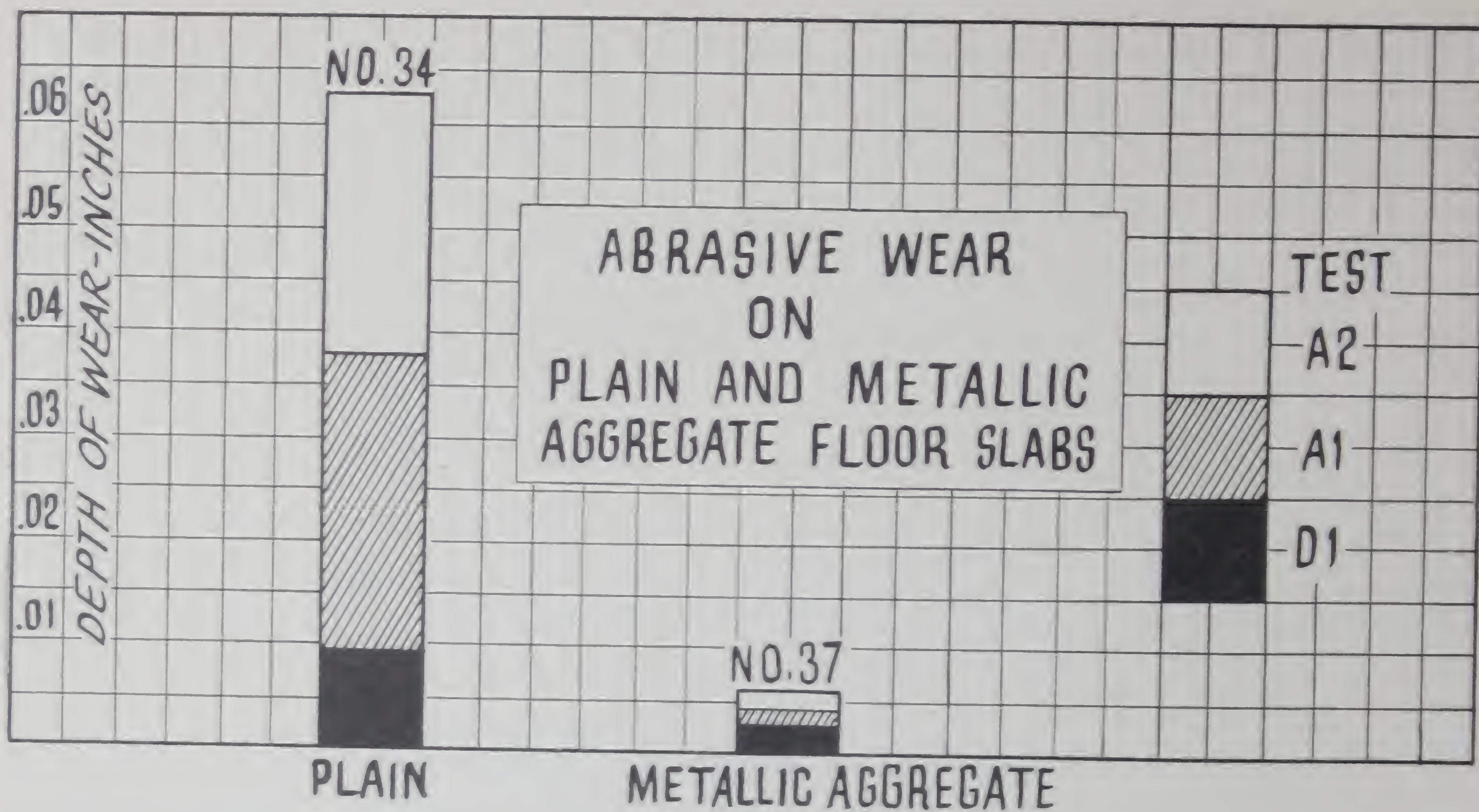
Pennsylvania Railroad Station, Euclid Avenue and East 55th Street, Cleveland, Ohio, floor laid in 1912. The portion of the floor in the foreground was laid without metallic aggregate, that in the background with metallic aggregate. The area in the background is subject to twice the amount of traffic as both incoming and outgoing traffic pass over it whereas only outgoing traffic passes over the area in the foreground.



No Metallic Aggregate — Metallic Aggregate

Relative conditions of the areas with and without metallic aggregate at the joint.

Fig. II



"Slab 37 coated with 0.9 lb. of metallic aggregate mixture per sq. ft. of surface showed the least wear of all slabs tested."

Slab No.	C/W	Total Water Gals/sk.	Vol. %	Flow %	Interval Placing to Trowelling	Storage Days Damp	Air	Surface Treatment
34 Sand A	1.73	6.5	27.9	60	2.5	6	21	None
37 "	1.73	6.5	27.9	60	2	6	21	2:1 Metallic Aggregate Cement—0.9 # /sq.ft.

WEAR TEST RESULTS

	5 Min.—no abrasive–D1 & D2 Wt. of Dust	Depth of Wear	With abrasive—.001 in. A1–10 Min.	A2–10 Min.	Pitting*	Remarks
34	40	9	29	25	E	Fairly dry
37	19	3	1	2	N	Readily finished Lowest wear all slabs

*E = Excessive
N = Negligible

Data from Research Paper RP 1252—Journal of Research—National Bureau of Standards by Schuman and Tucker.

Probably the first metallic aggregates, commonly called metallic hardeners, were simply ground iron to which little attention had been paid with respect to purity and grading.[2] It is fairly obvious that the principles which apply to the usual concrete aggregates apply, with slight modifications, to a metallic aggregate. The first step in the development of a satisfactory metallic hardener was taken in the direction of producing a material of proper size grading. With increasing knowledge of cement technology and improvements in floor-laying technique further improvements in size grading have been made. It was soon observed that metallic hardeners containing non-ferrous metals, particularly aluminum and zinc, would react with the alkali of the cement to form hydrogen. As this occurred during the hardening process blisters were formed which produced weak spots in the floor. (Fig. III.)

[2]Metallic Aggregates in Concrete Floors—E. W. Scripture, Jr. (J.A.C.I., Sept.-Oct. 1936.)

Fig. III

BLISTERS PRODUCED BY USE OF A METALLIC AGGREGATE CONTAINING NON-FERROUS METAL PARTICLES.

It further became apparent that the presence of oil, grease or similar water-repellent material in the aggregate would weaken the bond between the cement and the aggregate, decreasing the resistance.[3] (Fig. IV.)

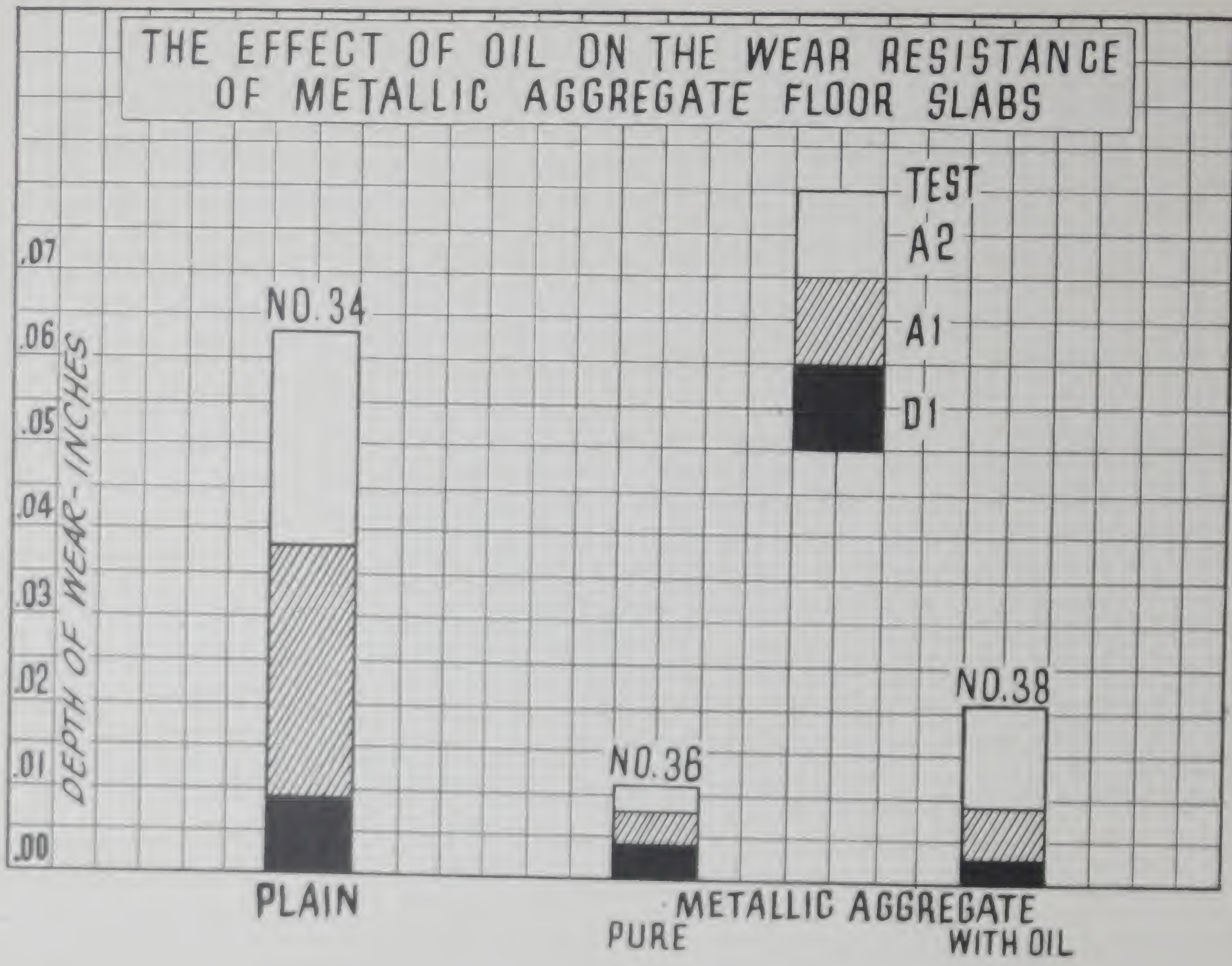
By suitable treatment of the metallic aggregate materials were produced which were free from these defects, that is, were properly graded, free from non-ferrous metal particles and free from oil and grease.

It may be mentioned here that all processes of treatment to remove impurities may not be suitable. It is possible to remove oil, grease, and non-ferrous metal particles by washing with strong alkali. The alkali is then removed by rinsing with water but unfortunately it is difficult, if not impossible, to remove all the alkali in this manner. A recent survey of a number of metallic hardeners, presumably manufactured by this process, showed that they contained varying amounts of alkali. Further, the presence of this alkali had a very marked effect, roughly proportional to the amount of alkali present, in reducing the compressive strength and abrasion resistance of the floor toppings made from these aggregates. (Fig. V and Table I.)

Pozzuolanic materials are known to improve the strength of concrete, and what is perhaps more important, its resistance to corrosion. They also improve workability and this is a matter of some significance in dealing with aggregates which may be rather harsh due to their shape. Fairly large effects may be secured with relatively small amounts when a reactive pozzuolana is used. A further improvement in metallic hardeners was the inclusion in them of a small amount of reactive pozzuolana. (Figs. VI and VII.)

[3]A Portable Apparatus for Determining the Relative Wear Resistance of Concrete Floors—Schuman and Tucker—Bureau of Standards Journal of Research, Vol. 23, Nov. 1939.

Fig. IV



No.	Proportions	Aggregate	C/W	Total Water content Gal/sk	Vol.	% Flow	Interval placing to Trowelling Hours	Storage Days Damp	Air	Surface Treatment
36	1:3	Sand A	1.73	6.5	27.9	60	2	6	21	2:1 Met. Agg. Cement 0.45 # /sq. ft.
38	1:3	Sand A	1.73	6.5	27.9	60	2	6	21	2:1 Met. Agg. (3% oil) Cement 0.45 # /sq. ft.
34	1:3	Sand A	1.73	6.5	27.9	60	2.5	6	21	No treatment

WEAR TEST RESULTS

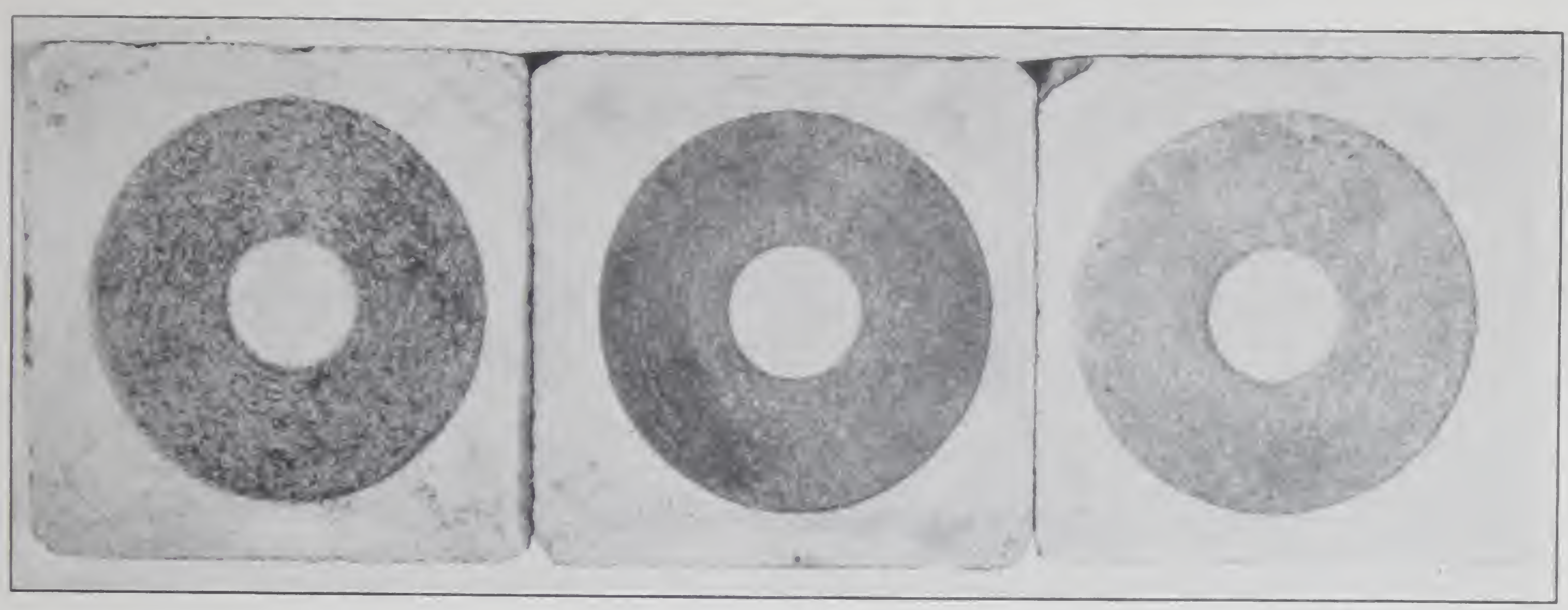
	Test D1 and D2 5 Min. No abrasive Wt. of Dust-g.	Depth of wear .001"	Test with abrasive Depth of wear Test A1 10 Min.	Test A2 2nd 10 Min.	Depth* of Pitting	Remarks
36	13	4	4	3	M	Fairly dry—finished readily
38	16	3	6	12	E	Oil causes pitting
34	40	9	29	25	E	Fairly dry—readily finished

*M = Moderate
E = Excessive

Data from Research Paper RP 1252—Journal of Research—National Bureau of Standards by Schuman and Tucker.

Fig. V

Effects of Alkalies on Abrasion Resistance



No. 2—.021″ Soluble salts .18% Alkaline	No. 1—.004″ Soluble salts .002% Neutral	No. 5—.028″ Soluble salts .08% Alkaline

TABLE No. I

Metallic Aggregate No.	Purity Oil and Grease	Soluble* Salts–%	Reaction to Litmus	Compressive Strength** Lbs. per sq. in. 3 days	7 days	Depth of Abrasion in.–10 Min.
1	Water absorbent	.002	Neutral	3020	5795	.004
2	" "	.18	Alkaline	2385	3660	.021
3	" "	.20	"	1910	3185	.010
4	" "	.23	"	1210	2705	.009
5	Repellent	.08	"	1910	3120	.028
6	Slowly absorbent	.10	"	1685	2385	.009

Strength of equivalent mix with sand aggregates

3 days	2320
7 days	4935

*Alkaline sulphates and carbonates.
**Mix—Cement 1 pt., Metallic Aggregates 2 pts. by weight—all at same consistency.

If a metallic hardener is considered as an aggregate differing from other aggregates only in that it has the extremely useful property of malleability, it will be realized that the same problems and principles apply to metallic hardener floors as do to other concrete floors or indeed to concrete generally. First among these is the problem of workability and this is perhaps aggravated by the rather angular shape of iron particles. Second is that of maintaining a low water-cement ratio to improve strength, durability, watertightness, and volume change characteristics. The last of these is especially important in floor work to prevent crazing and cracking at the surface which is the most vulnerable part of the floor. It

Fig. VI

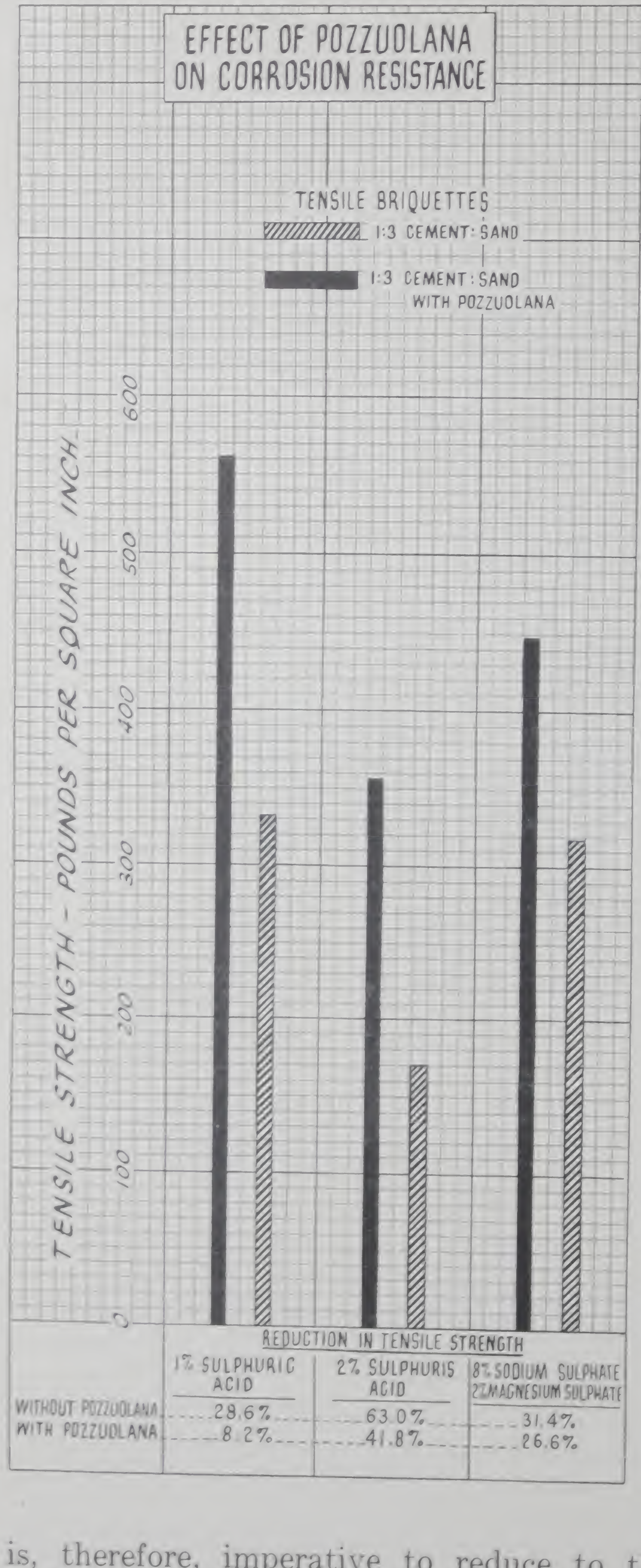
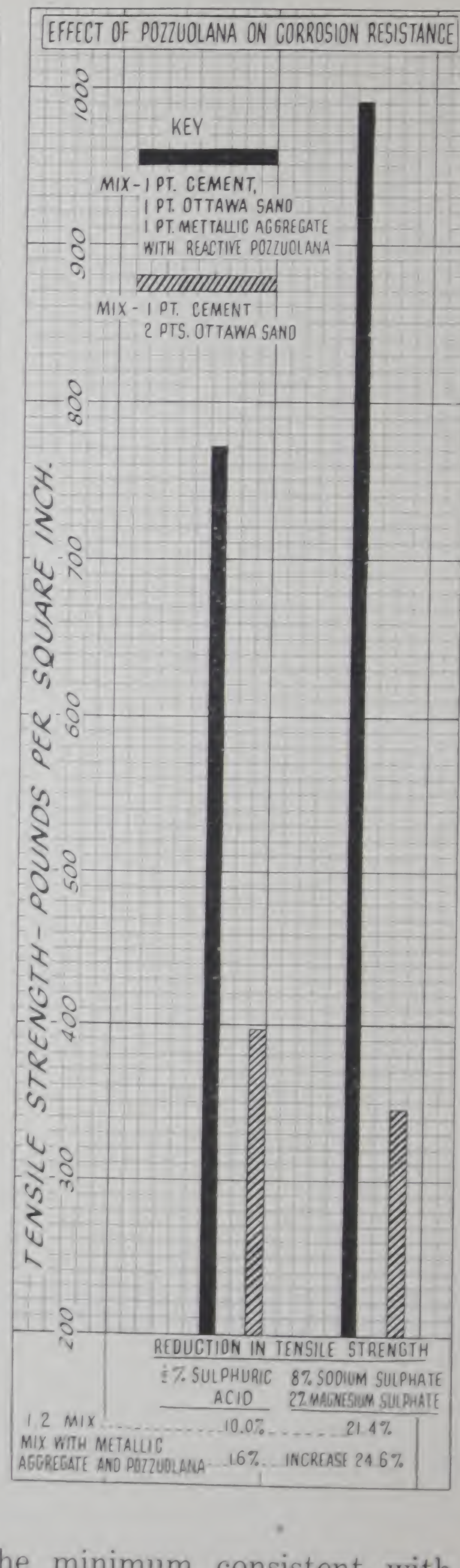


Fig. VII



is, therefore, imperative to reduce to the minimum consistent with workability and strength both the water and cement contents.

The finishing operations involved in producing a smooth, dense surface constitute a special condition not encountered in ordinary concrete work. Floating and trowelling tend to bring water and fines to the surface which

are sources of low strength and high volume change.[4] Consequently it is not only necessary to avoid overworking but also to have a cohesive mix which does not tend to segregate or bleed and which contains a minimum of fines.

There are several methods of laying concrete floors including the monolithic and two-course methods. Each has its advantages but these need not be discussed here as considerable information on this subject is available elsewhere. The use of a dry shake applied to the surface of the floor before it has hardened warrants some mention as this practice has been misunderstood and some prejudices have been formed.

At one time it was common but not good practice to lay floors with a rather wet mix and to dust on the surface to dry them up a "shake" of neat cement. The object was to shorten the time between placing and finishing and the result was excessive volume change with the attendant crazing and cracking. If, however, the floor is laid with a dry mix and a shake consisting of cement and aggregate in suitable proportions is used the surface of the floor is improved instead of impaired.[5] Volume change is not increased but may be reduced, strength is increased, finishing is facilitated by greater workability, and the density of the surface improved by better size grading at this point.

Metallic aggregates and colors have been applied to concrete floors for a period of over thirty years by the shake method with eminently satisfactory results. The purpose of so doing, besides the advantages enumerated above, is to reduce cost as both metallic aggregates and colors are relatively expensive compared with the other components of the mix.

CEMENT DISPERSION

Application of the principle of dispersion to hydraulic cements has recently assumed considerable importance in concrete construction and has found widespread use in the present defense building program. Dispersion of finely divided solid material in a liquid is not in itself new as it has been employed in ceramics, dyeing, and other fields. Dispersing agents are, however, specific in nature so that a reagent which acts to disperse some particular solid-liquid system may or may not act in a similar manner in some other system. Furthermore, an effective dispersing

[4]A Portable Apparatus for Determining the Relative Wear Resistance of Concrete Floors—Schuman and Tucker—Bureau of Standards Journal of Research, Vol. 23, Nov. 1939.

"The amount of floating and trowelling necessary in such cases sometimes brought free water to the surface (Slabs 93, 94 and 95). The wetter mortar mixes also showed surface water, especially if trowelled too soon (Slabs 1, 24 and 30). Although excess water was not the only cause of poor wear resistance, its appearance on the slabs, as noted in Table 2, usually was followed by poor wear resistance in the D1 test, for example slabs 24, 30, 93, 94 and 95."

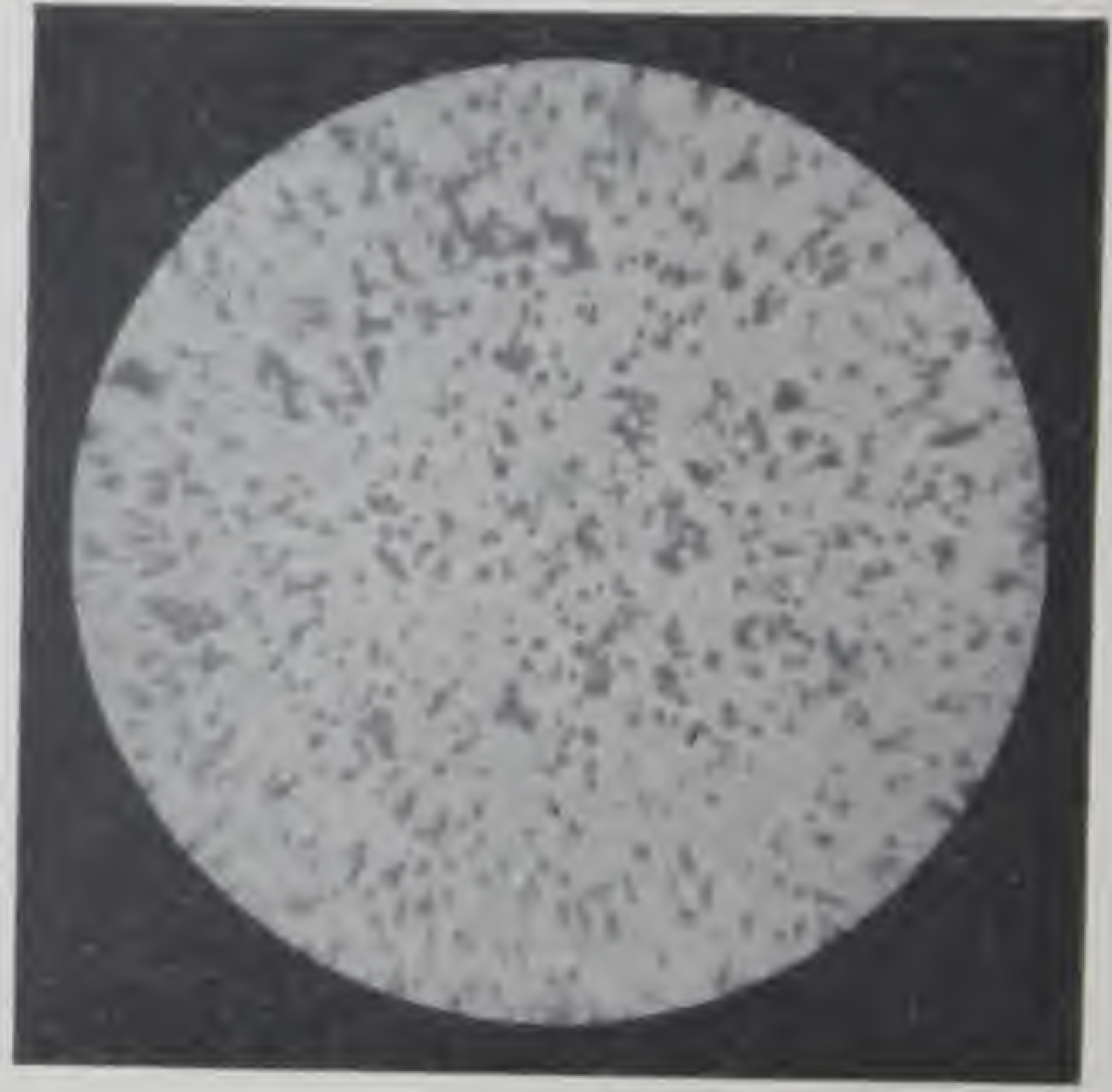
[5]Same reference as 4.

"The use of a dust coat also enables easier and earlier finishing in some cases, as for Slab 68 as compared with Slab 67. The reductions in depth of wear effected by the use of dust coats are considerable in all these tests, as seen in Fig. 5. The dust coats, even when trowelled into the surface immediately after placing reduced the depth of wear; but greater reductions were obtained by delayed trowelling. However, a large amount of cement dust coat, as on Slab 32 (1½ lb. per sq. ft.) resulted in pronounced crazing."

agent may interfere with other reactions of the system. The use of dispersion in the field of concrete and mortar has awaited the development of effective dispersing agents which would not interfere with the normal reactions of hydraulic cements. Such reagents were discovered about 10 years ago and since that time have been developed in the laboratory and in the field so that they are now established as a practicable means of considerable importance of improving the properties of concrete.

When portland cement is mixed with water the individual particles tend to gather together and stick to each other in clumps, i.e., the solid-liquid system is flocculated. This is due to lack of mutually repellent electrostatic charges on the cement particles. If a suitable dispersing agent is introduced into the mix the clumps are broken up and the cement then acts as individual particles, i.e., is dispersed. (Fig. VIII.)

Fig. VIII



Cement Suspended in Water

UNDISPERSED DISPERSED

Dispersion of the cement produces two important effects. The water which has been trapped within the particle clumps is released to become a part of the mixing or placing water. The surface area of the cement in contact with water is greatly increased since the particles are no longer in contact with each other. As a result of the first the amount of water required in the mix for a given consistency is less, i.e., the water-cement ratio is reduced. Since the value of the cement is dependent on a hydration reaction which is a surface phenomenon, the second effect which promotes more rapid and more complete hydration permits more efficient utilization of the cement. By the reduction in water-cement ratio and by the increase in surface area of cement available for hydration the potential value of the cement is more completely realized.

CEMENT DISPERSION AND METALLIC AGGREGATES

The effects produced by dispersion of the cement in concrete mixes have been described in previous papers (Research Papers Nos. 35 and 36). In relation to metallic aggregate shakes for floors the same general phenomena of cement dispersion are observable but their implications differ somewhat in detail.

In applying a "shake" composed of metallic aggregate and cement to a floor the concrete or mortar is placed with as low a water-cement ratio as possible and floated. The dry "shake" is distributed over the surface evenly and floated into the surface. Finishing is then carried out in the usual manner.

It is important that the concrete or topping mortar should be placed with a low water-cement ratio in order that the usual virtues of low water shall be realized in this part of the floor. It is possibly of even greater importance that water and fines shall not be brought to the surface during floating.[4] It is also essential that the metallic "shake" be applied at the proper time. This means that it must not be applied when the floor is too wet or soft; otherwise the heavy metallic aggregate will sink below the surface. This would nullify the advantages of using a metallic aggregate which is intended to impart wearing qualities to the surface. On the other hand, the shake must be applied before the time when the floor becomes so hard or so dry that it is no longer possible to float it into the surface and make it an integral part of the floor. Otherwise the metallic surface will tend to scale off under traffic.

Cement dispersion, which maintains workability in a mix containing less water, extends the period during which the "shake" may be applied with satisfactory results since it will be possible to float the "shake" into the floor when the latter has dried out beyond the point at which it would otherwise be possible to do so. By the use of a dispersing agent in the shake floating in can be successfully carried out on drier floor slabs so that the concrete or topping mortar to which the shake is to be applied can be placed at a lower water-cement ratio. (Figs. IX and X.)

Due to the greater surface area of cement exposed the "shake" is fattier and more water retentive. As a consequence finishing is facilitated and it is possible to use a lower proportion of cement in the shake. Furthermore there is less tendency for water and fines to be brought to the surface during the finishing operations.

The results of dispersion of the cement in the shake spring essentially from the greater workability with reduced water and the exposure of a larger surface area of the cement to the water. In the plastic state they are:

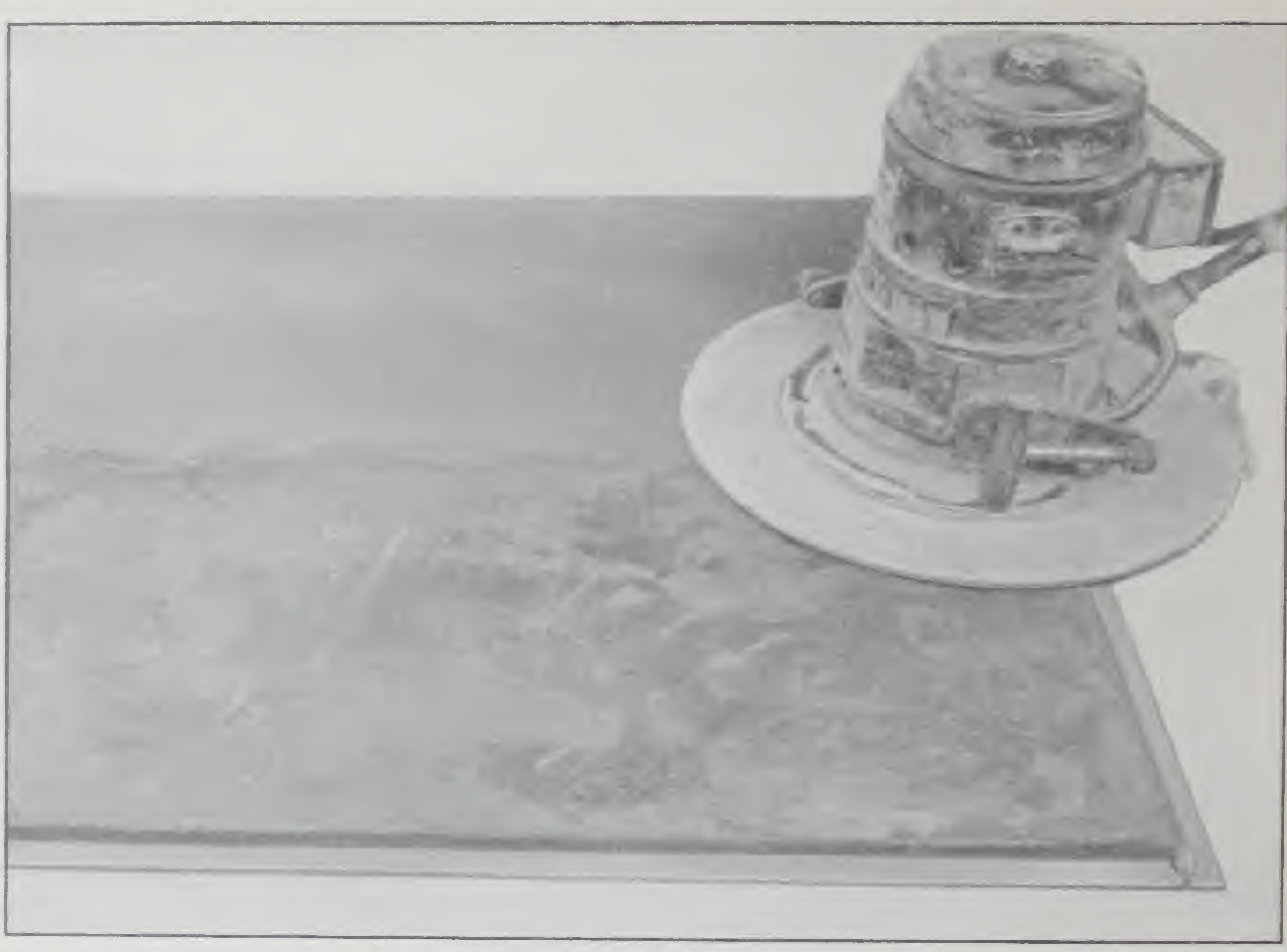
1. Ability to incorporate the metallic aggregate in the surface of the floor with concrete or topping mortar of lower water-cement ratio. (Figs. IX and X.)

2. Ability to use a lower proportion of cement in the shake. (Table II.)

3. Reduced tendency to bring fines and water to the surface during finishing.

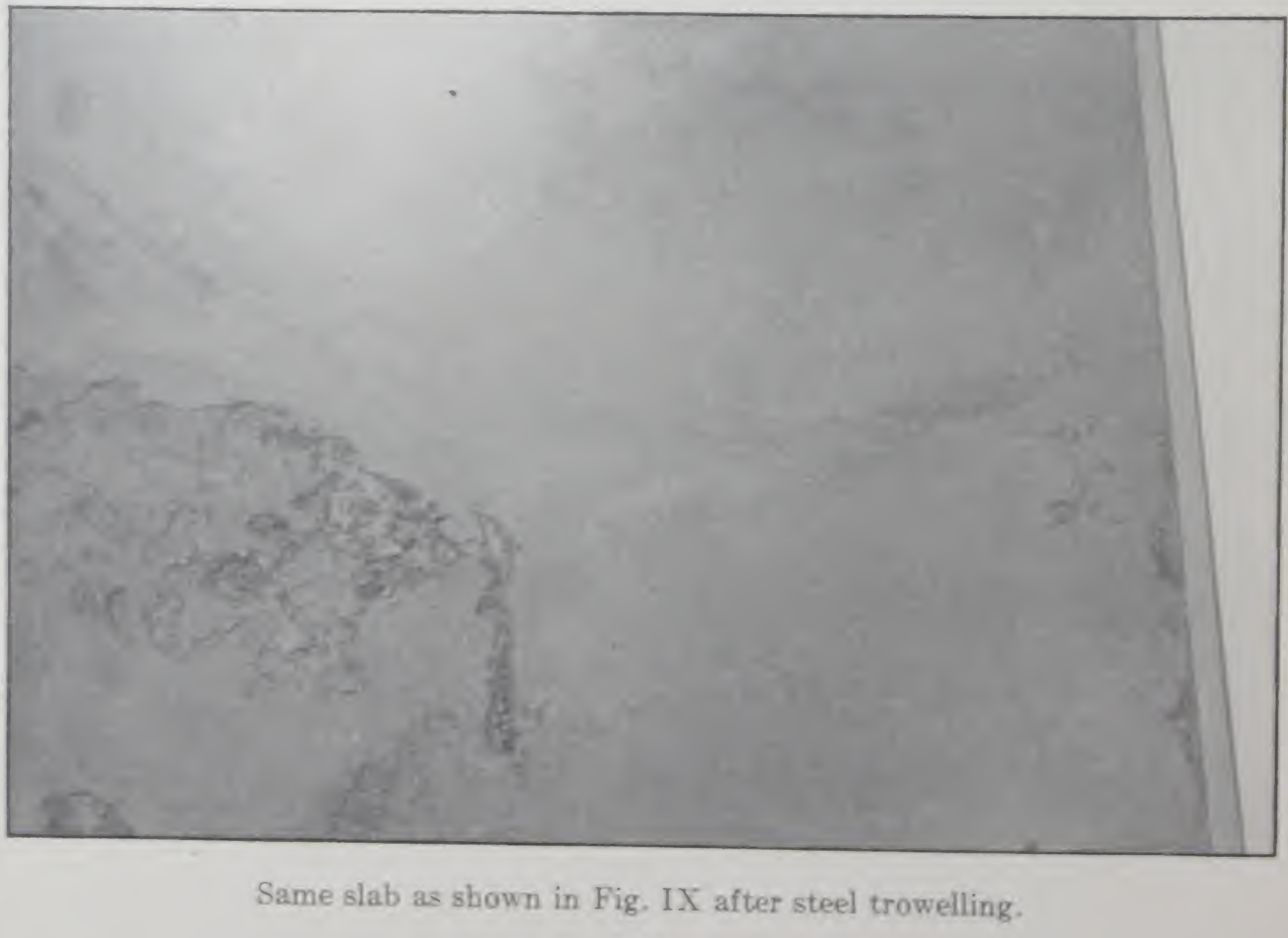
4. Easier finishing.

Fig. IX



Back half of slab—60 # per 100 sq. ft. metallic aggregate with dispersing agent.
Front half of slab—60 # per 100 sq. ft. metallic aggregate without dispersing agent.
Both halves of slab on same topping mix and mechanically floated equal length of time.

Fig. X



Same slab as shown in Fig. IX after steel trowelling.

As far as the finished floor is concerned these advantages in the behavior of the "shake" during the plastic stage result in:—

1. Increased strength and resistance to abrasion. (Table III, Figs. XI and XII.) — (lower water-cement ratio and greater surface area of cement exposed to hydration.)

2. Reduced porosity (lower water content) (Table No. IV).

3. Increased durability (lower water and increased hydration). (Fig. XIII.)

4. Lower volume change and less tendency to cracking, checking, and crazing (lower water and lower cement content).

5. Better finish (improved workability).

TABLE No. II

Effects of Cement Proportions in Shakes of Metallic Aggregate in Concrete Floors — J.A.C.I., Sept.-Oct., 1936

Lbs. per 100 sq. ft. Metallic Aggregate	Cement	Depth of Abrasion in inches	Height of drop (in ft.) to cause impact failure: Surface Cracked	Broke	Average
30	22½	.003	4.5	6.3	5.4
30	15	.002	6.1	6.8	6.5
30	7½	.004	6.4	7.4	6.9
60	45	.003	6.5	7.0	6.8
60	30	.003	6.0	6.4	6.2
60	15	.003	6.0	6.5	6.3

With the lighter shake the 4:2 proportion of metallic aggregate to cement shows markedly higher abrasion resistance than either the higher or lower proportions. With the heavier shake (60# per 100 sq. ft.) the differences are small but the 4:2 and 4:1 proportions are slightly better than the 4:3 mix. Differences in impact resistance are all so small that they do not seem to have any significance except that the lighter shake cracks at a very low impact with the rich 4:3 shake. It is recognized that excessively rich mixes are not desirable because of high shrinkage and the danger of crazing and checking. These tests show that the leaner mixes are at least as good and generally better in resistance to abrasion and impact than the commonly used rich shake. The limit in leanness is, therefore, determined not by strength but by workability. It was noticeable in preparing the test slabs of this series that the 4:1 shake was difficult to finish properly but the 4:2 mix was satisfactorily workable. The latter would seem to be the most desirable proportion of metallic aggregate to cement.

TABLE No. III

Effect of Dispersing Agent on Strength and Abrasion Resistance of Metallic Aggregate

Metallic Aggregate	Compressive Strength Lbs. per sq. in. 7 days*	Abrasion Resistance Depth of Wear - in.
Without Dispersing Agent	5795	.006
With Dispersing Agent	7480	.004

*Mix—Cement 1 pt. by wt.
Metallic Aggregate 2 pts. by wt.
Equal consistencies

Fig. XI

Method of Testing Abrasion Resistance

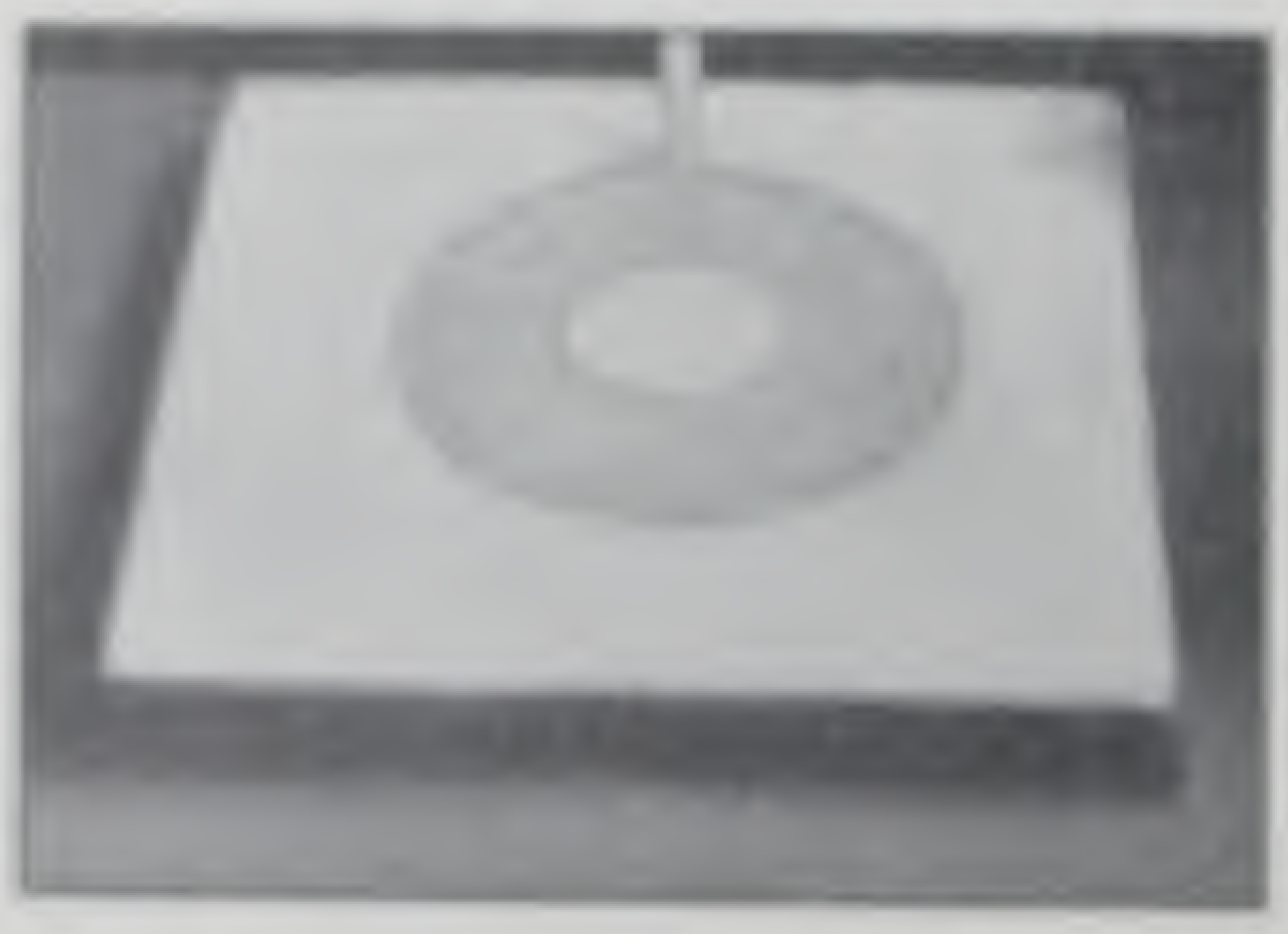
Abrasion Head to be run over test slab at 240 R.P.M. for 20 minutes under 100 lbs. per square inch pressure.

Drill Press fitted with weights, Abrasion Head and slab to be tested in place

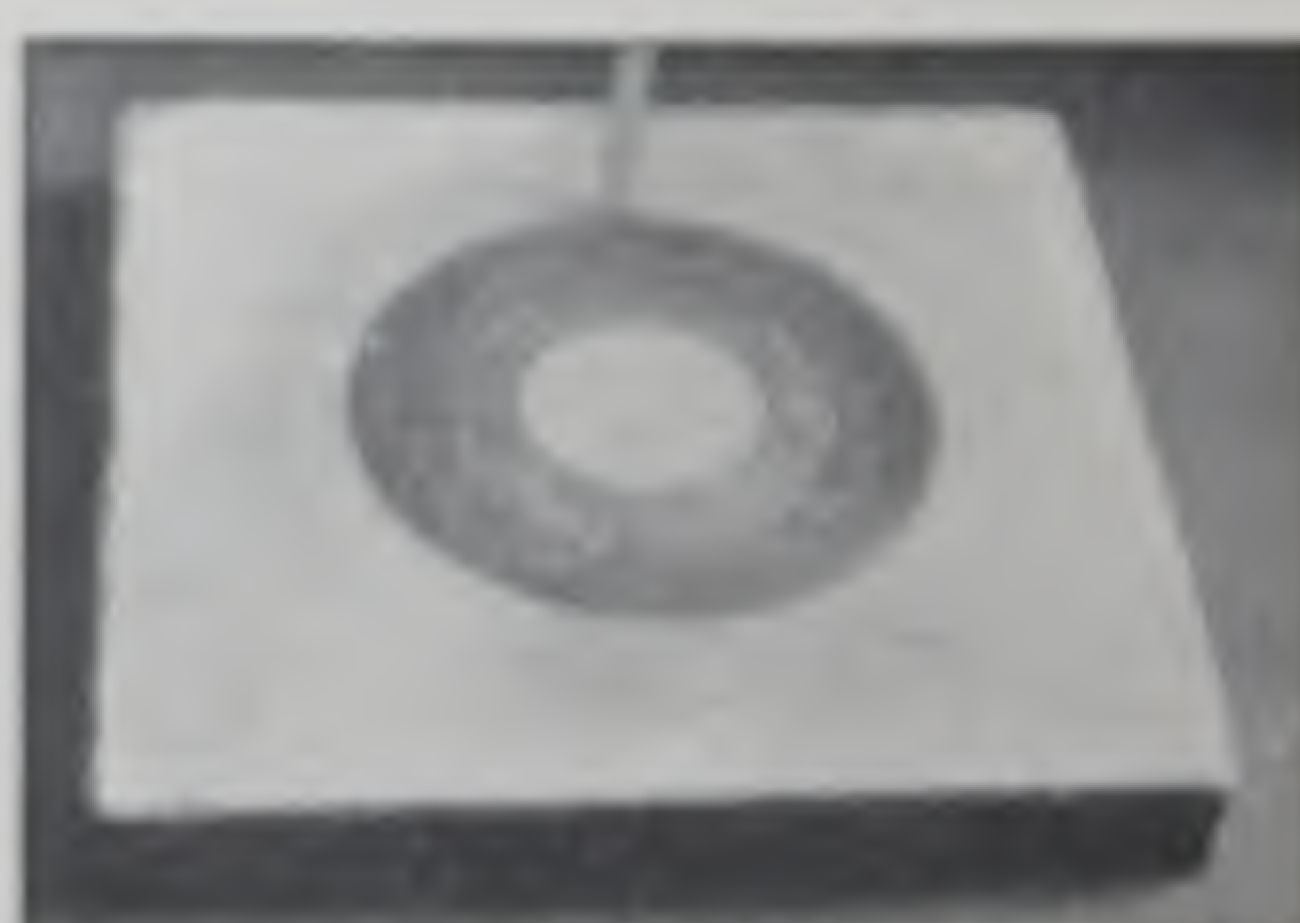
Bridge Micrometer used in measuring abrasion of test slabs.

Fig. XII

Abrasion Resistance of Metallic Aggregate with Dispersing Agent



No shake:
Depth of Abrasion .032 in.



Metallic Aggregate with Dispersing Agent:
Depth of Abrasion .006 in.

Both slabs placed at same time, mechanically floated and trowelled. Moist cured 14 days.

TABLE No. IV

Effect of Dispersing Agent on Porosity

Metallic Aggregate*	Absorption—% by wt. 1 hour	Absorption—% by wt. 24 hours
With Dispersing Agent	2.0	2.7
Without Dispersing Agent	3.3	3.8

*Mix—1 pt. cement, 2 pts. Metallic Aggregate by weight.

Fig. XIII

Undispersed Cement - 150 Cycles of Freezing and Thawing, Loss in Weight - 73%

Dispersed Cement - Concrete of Same Design and Consistency 150 Cycles of Freezing and Thawing - Loss in Weight - 10%

ECONOMICS OF CONCRETE FLOORS

It is difficult to make any very definite statements regarding the economics of concrete floors because costs vary widely in different localities. The types and quality of these floors also vary to meet the service conditions. For example it is obvious that a floor which is suitable for light foot traffic will be inadequate for heavy trucking.

There is no question that the use of a metallic aggregate, in a given type of floor, will add to the cost of that floor. The actual cost of the metallic aggregate must be added and also a small cost for the two extra operations of distributing and floating the "shake". This cost will be more or less offset by the easier finishing of the floor.

Another factor which should be taken into consideration is that the cost of a monolithic floor with a metallic aggregate shake will be lower than that of a two-course floor without the shake. The objective sought in laying the two-course floor is to secure greater wear resistance by using a stronger and richer mix for the topping. Such a floor is less wear resistant

than the monolithic floor with metallic "shake" and owing to the richness of the mix has a higher volume change and hence tendency to cracking and crazing.

The cost of a 6″ monolithic concrete slab in place may be taken as approximately 17c per sq. ft. That of a 5″ slab with 1″ topping will be about 20c per sq. ft. The cost of applying the metallic "shake" will be about ½c per sq. ft. for light "shakes" and up to 1c per sq. ft. for the heavier "shakes". These costs will, of course vary with the size of the job and with local conditions but they may be taken as a basis of comparison. The cost of a good quality metallic aggregate (with cement dispersing agent) amounts to about 1½c per sq. ft. for 30 # per 100 sq. ft. which is the lightest practicable "shake". Larger amounts of metal in the surface will cost correspondingly more. Costs of various types of floors on this basis are given in Table No. V.

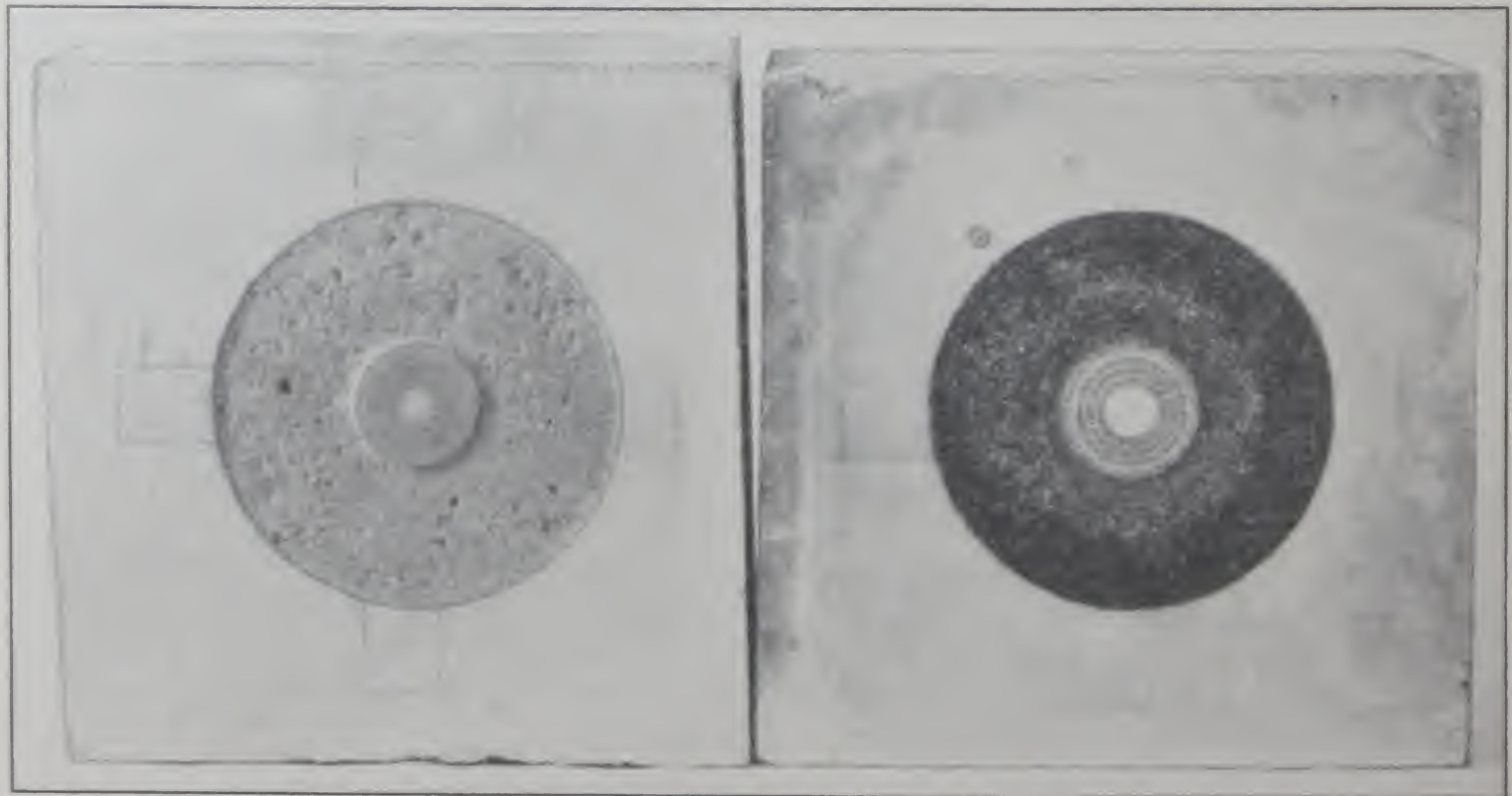
TABLE No. V

	Costs — Cents per sq. ft.	
Metallic Shake	Monolithic	Two-course
None	17	20
30 lbs. per 100 sq. ft.	19	22
60 lbs. per 100 sq. ft.	21	24
90 lbs. per 100 sq. ft.	22½	25½
120 lbs. per 100 sq. ft.	24	27

For light service the monolithic floor with the minimum shake actually costs less than the two-course floor without metallic aggregate and has greater wear resistance. (Fig. XIV.) With the lightest shake the increased cost of the two-course floor is only 10% greater when metallic aggregate is used while the wear resistance is increased many times.

Fig. XIV

Abrasion Resistance of Two-course Floor vs. Monolithic Floor with Metallic Aggregate



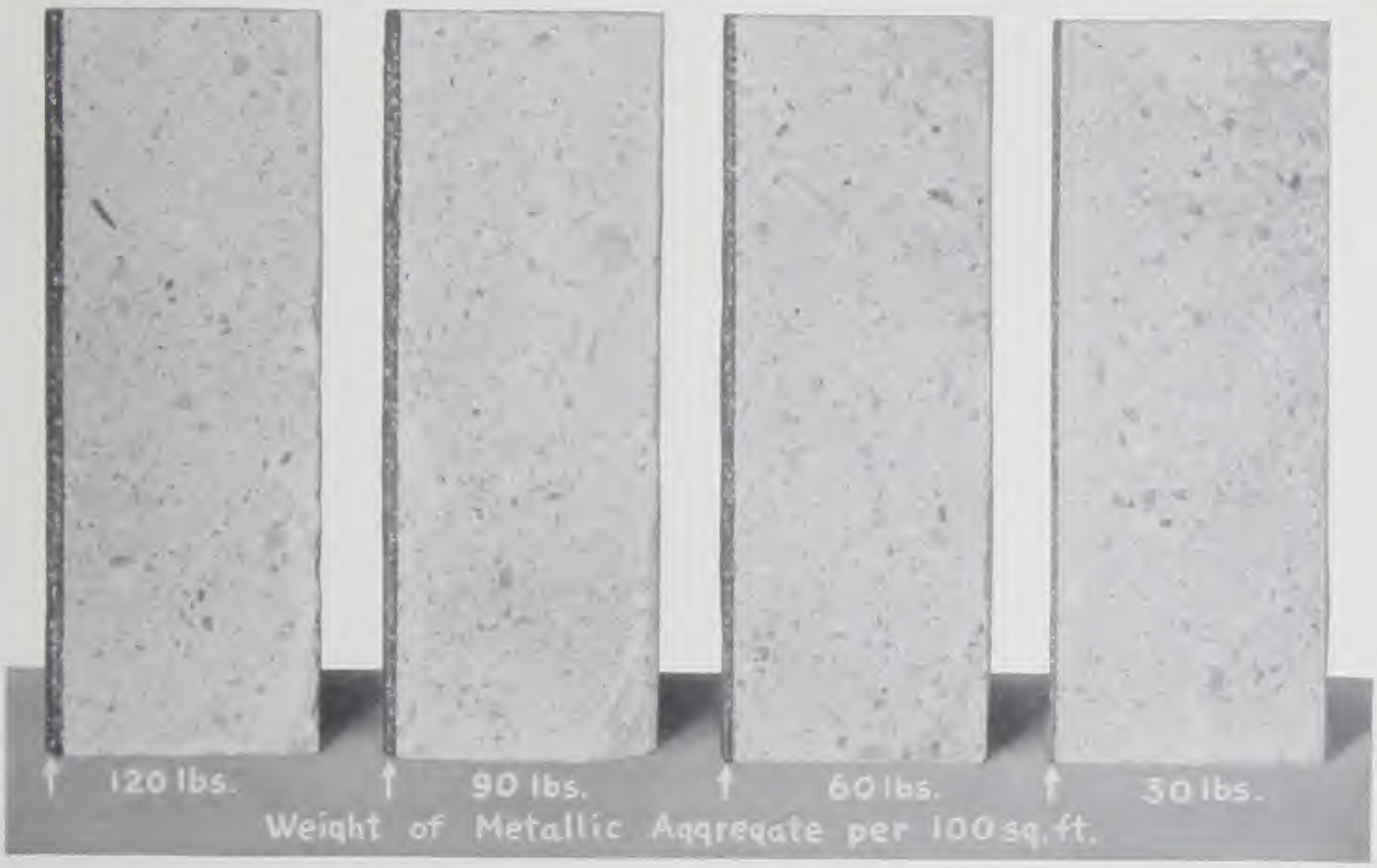
PLAIN
Base slab 1:2½:3½ Concrete
Topping 1:2 Mortar
Depth of Abrasion (15 min.) .0370″

METALLIC
Monolithic slab 1:2½:3½ Concrete
Shake 1 pt. Cement, 2 pts. Metallic Aggregate
Depth of Abrasion (15 min.) .0099″

With the heavier shake the costs will naturally increase but the only justification for the use of the heavier shakes is that, under the contemplated conditions, the floors without metallic aggregate or with the minimum shake will not give satisfactory service. (Fig. XV.)

Fig. XV

Metallic Aggregate Shakes of Varying Thicknesses



*Application of a shake of this weight is made by a special process.

From a purely economic point of view the lowest cost floor which may be expected to give satisfactory service under light traffic is the monolithic floor with 30 lbs. metallic aggregate per 100 sq. ft. For more severe service the small increases in cost of the heavier shakes are much more than justified by the greatly increased resistance to wear. (Table VI.)

TABLE No. VI

Lbs. per 100 sq. ft. Metallic Aggregate	Depth of Abrasion in Inches	Height at Drop (in ft.) to cause impact failure Surface Cracked	Broke	Average
30	.006	5.0	6.4	5.7
60	.006	5.5	6.5	6.0
120	.003	6.8	7.8	7.3
150	.004	6.2	7.0	6.6

This very consistent series of slabs shows that resistance to abrasion, to cracking and to breaking on impact increase with the amount of metallic aggregate applied up to 120 lbs. per 100 sq. ft. Above this point resistance to these forces begins to fall off, probably due to the limitations of the method of application.

It should be noted that, although there is some gain in rate of abrasion with the heavier shakes, the advantage in longer life should be even more marked. For example, while the rate of wear is only half as great with the 120-lb. shake as with the 30-lb. shake, the depth to be worn through is four times as great. It is also worthy of mention that the metallic layer becomes an integral part of the topping, showing no tendency to chip off under impact at loads up to the breaking point of the slab.

Summary—

The first requirement in a concrete floor is resistance to wear and this may be most effectively secured by incorporation of a metallic aggregate as an integral part of the surface. It is necessary that this metallic aggregate shall be properly graded in size and of a high degree of purity. In order, however, to realize the full benefits of a metallic aggregate floor a suitable cement dispersing agent should be combined with the aggregate to permit its application to the driest possible concrete or mortar and to extend the period during which application can be made successfully.

In the incorporation of a metallic aggregate in the floor surface best results can only be secured if the shake is highly workable and has the lowest possible tendency toward segregation, bleeding, and the formation of laitance. These properties insure a smooth dense finish with a minimum expenditure of labor and without the formation of a weak dusting layer at the surface by the working up of water and fines.

High volume change in a cement floor leads to cracking, checking and crazing. The tendency toward these undesirable phenomena may be greatly reduced, if not eliminated, by reduction of both the water and the cement required to produce a readily workable "shake". This again is secured by the use of a cement dispersing agent.

Low porosity and resistance to corrosion are also desirable in most concrete floors. These are produced in part by having a workable mix which can be properly finished and in part by reduction in the amount of water required for workability, both attained through cement dispersion.

In selecting the type of concrete floor to be installed due consideration should be given to service conditions. For light traffic and mild exposure where this type of construction is practicable a monolithic metallic aggregate floor can be laid at lower cost than the usual plain two-course floor which is less wear resistant. For heavier traffic and more severe exposure, under which the ordinary floor does not stand up satisfactorily, thicker metallic surfaces may be used at somewhat increased costs but the increased durability of such floors is relatively much greater than the added cost.

CEMENT DISPERSION AND NON-METALLIC FLOORS

There would seem to be little doubt that for a given cost and a given type of service the most satisfactory and most economic floor is one in which more or less metallic aggregate has been incorporated in the surface. Under some circumstances a metallic aggregate may not be desired so that the relation of cement dispersion to plain concrete floors should also be examined.

The effects of cement dispersion on the properties of concrete generally have been discussed elsewhere (Research Paper No. 35). These same general principles are equally applicable to concrete when used specifically for floors. The beneficial effects of cement dispersion on the properties of concrete during its plastic stage such as increased fattiness and water retentivity, reduced water, segregation, bleeding, and shrinkage before hardening are equally important in concrete used for floor construction or more important. So also are the increased uniformity, strength, watertightness, and durability, the decreased volume change and permeability which are realized in the hardened concrete through dispersion of the cement.

The economics of cement dispersion in concrete have been treated at length in another paper (Research Paper No. 36). These same principles apply to concrete regardless of the purpose for which it is to be used including the laying of floors. It follows that a floor of given quality at lower cost or at a given cost a higher quality floor can be produced by designing the concrete mix with a suitable dispersing agent.

While the previous papers, strictly speaking, were confined to a consideration of concrete mixes, the same principles are applicable to mortar mixes which are commonly used for floor toppings in two-course construction. This is illustrated by the data in Table VII and Figs. XVI and XVII.

TABLE No. VII

Strength of Mortars with Dispersed and Undispersed Cements

Condition	g. Cement	g. Sand	g. Pea Gravel	c.c. Water	Compressive Strength Lbs. per sq. in. 3 days	7 days	28 days
Undispersed	1200	1200	1800	485	3755	5315	6145
Dispersed	1200	1800	2500	485	3940	5955	6905

Slumps of Mortars with Dispersed and Undispersed Cements

Mix	Condition	W/C (Gals./sk.)	Slump (in.—6″ Cone)
1:1:1½	Undispersed	4.65	1¾
1:1½:2	Dispersed	4.65	1¾

Fig. XVI

Resistance to Freezing and Thawing and to Corrosion of Mortars with Dispersed and Undispersed Cement

1:5 Mortar Specimens after 100 Cycles of Freezing and Thawing

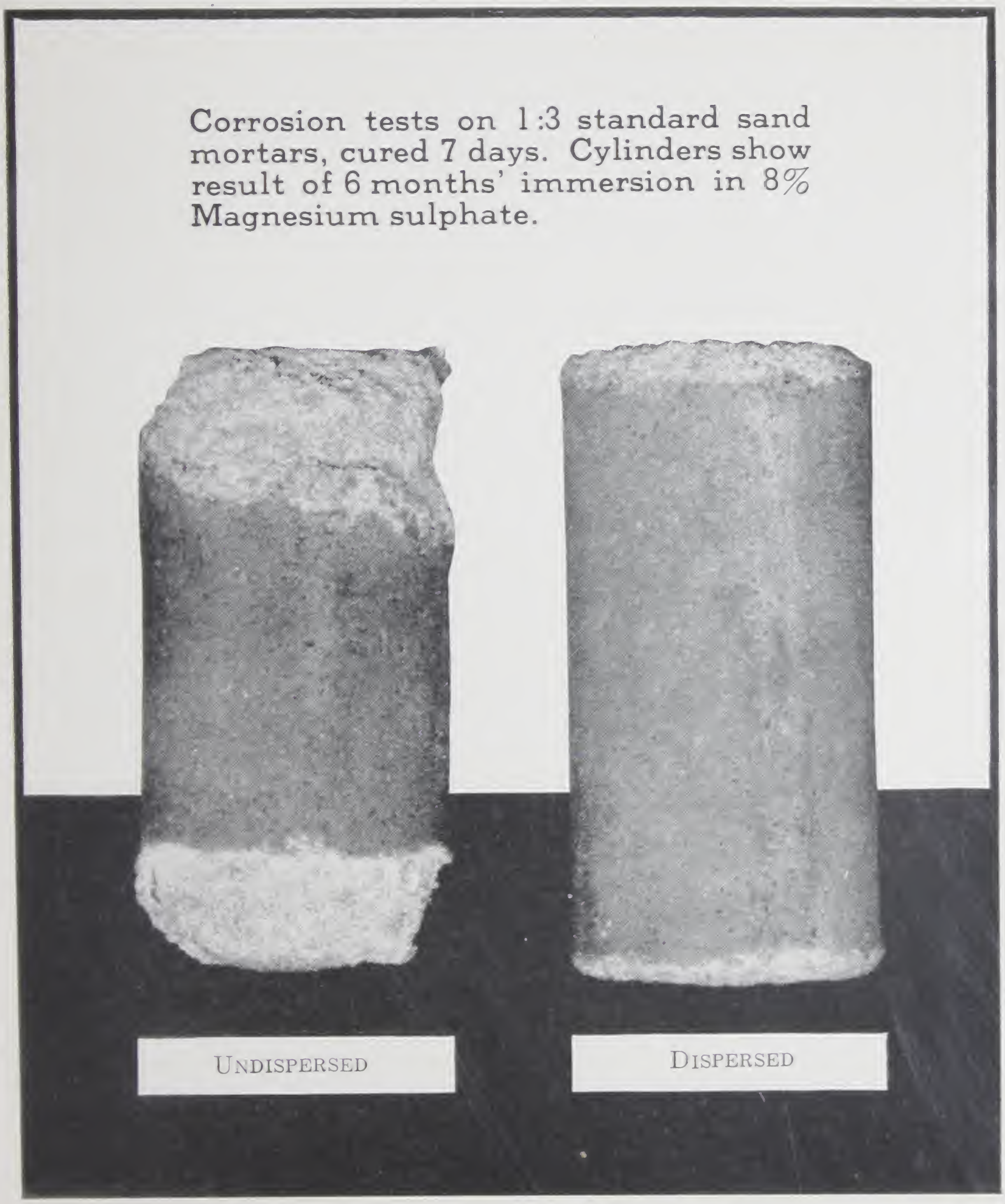
Original size of beams shown by dotted outlines.

DISPERSED

UNDISPERSED

Mix (by wt.)	Modulus of Rupture Lbs. per sq. in. 50 cycles	Modulus of Rupture Lbs. per sq. in. 100 cycles	Compressive Strength Lbs. per sq. in. 50 cycles	Compressive Strength Lbs. per sq. in. 100 cycles	Loss in Weight—% 50 cycles	Loss in Weight—% 100 cycles
1:3 Undispersed	...	732	....	5300	....	2.3
1:3 Dispersed	...	787	....	5350	....	1.4
1:5 Undispersed	330	131	1560	1280	16.4	41.0
1:5 Dispersed	500	371	1720	1640	12.8	24.7

Fig. XVII



Consequently, if it is proposed to design a concrete floor without a metallic aggregate the most economical means of so doing is to design the mix with a cement dispersing agent whether the mix is a concrete mix for a monolithic floor or a base slab or a mortar mix for a topping.

In laying floors and in other flat slab construction the time of the finishing operation is of some importance whereas no such considerations apply to most other types of construction. Under most, though not all, conditions a more rapid hardening of the floor will reduce finishing costs. Therefore, for floors it seems desirable to use a cement dispersing agent which has a slightly accelerating effect rather than one, more suitable for most ordinary construction, which does not affect the setting of the concrete.

It has been mentioned that under certain circumstances a metallic aggregate floor may not be desired and it may be well to examine this question a little more closely. The three possible reasons for the choice of a plain floor in preference to a metalling aggregate floor would appear to be economy, lack of resistance of the metallic floor to the exposure conditions and a possible hazard created by the metallic aggregate.

As far as economy is concerned the only type of floor which is less costly than a light shake (30 # /100 sq. ft.)[6] of metallic aggregate on a monolithic floor is a plain monolithic floor. Such a floor can be expected to give satisfactory service only when traffic will be very light or non-existent, when the structure is intended for only temporary use, or where the floor will be covered. Under any other conditions the most inexpensive floor is a monolithic floor with a shake of 30 # /100 sq. ft. of metallic aggregate. Such a floor is preferable to a plain two-course floor. In some cases the monolithic type of construction may not be practicable. Two-course construction has the advantage that for suspended slabs a base may be laid as the building progresses and a topping placed after the building has been enclosed. It is also somewhat easier to secure good levels. For slabs placed on the ground monolithic construction would seem to be generally feasible.

A metallic aggregate floor will resist any conditions which a plain concrete floor will resist. Portland cement is readily soluble in acid and concrete floors are not suitable under acid conditions. The fact that iron is also soluble in acid is not material since, if the cement matrix is attacked, it makes little difference whether the aggregate is soluble or insoluble in acid. The rate of attack of acid on an iron aggregate is slower than the rate of attack on the cement. Metallic aggregate floors are not recommended under acid conditions except where the attack on the floor due to traffic is more important than that to be expected from a mild acid condition. Under other forms of corrosive attack the metallic aggregate floor may be expected to be more resistant than a plain floor due to higher strength and lower porosity (cf. Figs. VI and VII). Exposed to the weather some oxidization of the metallic aggregate may be expected but this has no deleterious effect on the wearing qualities. The slightly rusty appearance may, in a few cases, be objectionable but it will not be noticeable on a surface subject to traffic.

It has been thought that the use of metallic floors has been precluded in certain industries where the introduction of iron particles into the product would be objectionable. This is the case, for instance, in the ceramic industry in the manufacture of white ware. This belief is unfounded because metallic aggregate floors do not wear in such a manner that metallic particles are dislodged. Due to the malleable character of the iron, as previously pointed out, the metal particles tend to flatten out and become more firmly fixed in the floor. A number of installations in whiteware plants have been entirely successful and have caused no iron spots. Certain materials are said to be sensitive to the presence of a metallic surface, constituting a hazard. It is for this reason the metallic aggregate floors have not been used in plants for the manufacture of photographic film.

A metallic aggregate floor would appear to be the most satisfactory and economical type in almost all cases where a concrete floor is to be used. There are a few circumstances under which it might be undesirable to install such a floor, but in such instances the most economic concrete

[6]A shake of 30 # per 100 sq. ft. is selected as the minimum amount of aggregate to be used in any case because this is about the amount of metal required to form a substantially continuous layer over the floor one particle thick.

floor can be produced with concrete or mortar mixes designed with a suitable cement dispersing agent.

SURFACE HARDENERS

Although the so-called surface hardeners are in no way related to cement dispersion, consideration of the selection of the most suitable concrete floor for any particular purpose would not be complete without some mention of these materials. The surface hardeners fall into two groups:—those which consist of some chemical which reacts with the lime in the cement to form insoluble compounds and those of an oily or resinous nature which form more or less impermeable films over the surface.

The most common chemical used as a surface hardener is magnesium fluosilicate. This compound presumably reacts with the lime of the cement to precipitate insoluble magnesium hydroxide, calcium fluoride and calcium silicate. It is sold under a number of trade names either as a solution in water or in the crystalline form. Zinc fluosilicate and sodium silicate are also used in a similar manner. The effectiveness of these compounds depends on penetration of a water solution into the surface of the concrete and deposition of the insoluble precipitate in the surface pores. With a soft porous floor, due to use of excess water in laying the floor or to lack of curing or to some other cause they will effectively decrease porosity and increase wear resistance (Table No. VIII).

TABLE No. VIII

Abrasion Resistance of Cured and Uncured Floor Slabs With and Without Magnesium Fluosilicate Treatment

Treatment	Depth of Abrasion—Inches Cured Slabs	Depth of Abrasion—Inches Uncured Slabs
None	.013	.020
Magnesium Fluosilicate Solution A*	.011	.016
Magnesium Fluosilicate Solution B**	.013	.016

*Made up from magnesium fluosilicate.
**Purchased in the open market as a floor hardener.

Penetration is, however, limited to a very thin surface layer in any case and such treatments cannot be considered permanent or as having any lasting effect. Where a good concrete floor, with or without metallic aggregate, has been properly laid and cured they have no beneficial effect. This has been shown by tests made at the National Bureau of Standards (Table IX and Fig. XVIII).

TABLE No. IX[7]

No.	Treatment	Damp	Air	Wt. Dust g.	Depth of abrasion—.001 in. No abrasive 5 Min.	No abrasive 10 Min.	Abrasive 10 Min.	Pitting*
78	None	6	21	28	6	15	11	M
97	3 coats high SiO_2 water glass	6	20	27	6	20	18	M
98	3 coats low " " "	6	21	27	8	16	16	M
99	3 coats magnesium fluosilicate	6	21	27	6	15	13	M
79	None	0	28	81	15	45	26	E
100	3 coats water	0	28	79	15	30	22	M
101	3 coats high SiO_2 water glass	0	28	66	14	32	31	E
102	3 coats low " " "	0	28	54	10	26	24	E
103	3 coats magnesium fluosilicate	0	28	53	10	30	30	E

1:2 Mix — Sand B
C/W — 2.26
Gals./sk 5.0
Vol. Water 28.6

*M - Moderate
E - Excessive

[7]Data from Research Paper No. 1252, Nat. Bur. of Stds.

Fig. XVIII

Effects of Liquid Surface Treatments on Abrasion

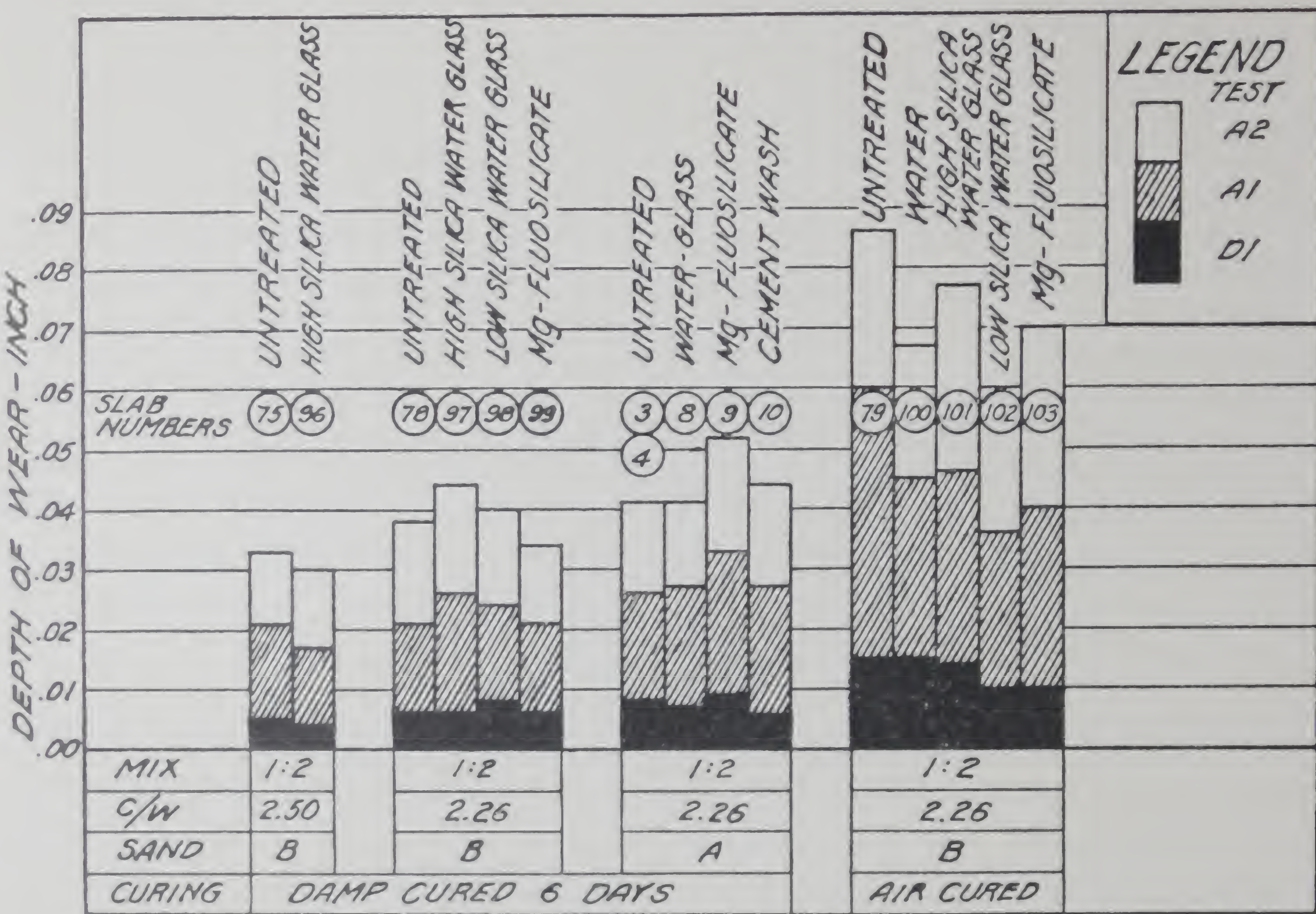


Fig. XVIII shows the depths of wear for the treated slabs in the D1, A1, and A2 tests in comparison with the depths of wear of untreated slabs. The tests show that the liquid surface treatments did not produce a significant increase in wear resistance of damp-cured slabs but produced an improvement in slabs that had not been damp-cured. The application of water instead of the solution reduced the total depth of wear to some extent.*

*Data and discussion from Research Paper RP 1252—Journal of Research of National Bureau of Standards, Vol. 23, November, 1939, by Louis Schuman and John Tucker, Jr.

Such liquid hardeners have been promoted on good floors, where they serve no useful purpose, by the device of scratching a new floor surface. Drawing a sharp instrument over a new floor will cause a small amount of dust to rise but this is perfectly natural and does not necessarily indicate any deficiency in the floor. When a floor is hard trowelled a thin skin of cement is brought to the surface and will dust on scratching. This film is soon worn off and does no harm.

It has also been proposed to add surface tension reducing agents to these liquid hardeners. The idea is that by reducing the surface tension greater penetration will be secured. This does not appear to be the case as is illustrated by the data in Table No. X, where the results on abrasion resistance secured with and without surface tension reducing agents are shown. This is probably because the magnesium fluosilicate reacts immediately with the free lime at the surface filling the pores and preventing further penetration of the solution regardless of its surface tension.

TABLE No. X

Effects of Surface Tension Reducing Agents on Liquid Hardeners

Treatment	Depth of Abrasion—Inches Cured Slabs	Depth of Abrasion—Inches Uncured Slabs
None	.013	.020
Magnesium fluosilicate solution	.011	.016
Same with Surface Tension Reducing Agent A	.010	.016
Same with Surface Tension Reducing Agent B	.014	.016
Commercial Product*	.013	.016

*A commercial liquid floor hardener purchased in the open market which is advertised as containing a surface tension reducing agent.

The film forming treatments may serve some purpose if they are substantially impermeable and resistant to corrosive solutions which will come in contact with the floor. Their only utility is in protecting the cement from solutions which would otherwise attack it. Such films are formed on the surface or in the superficial pores only. Penetration into a good concrete floor is negligible although the contrary is often suggested. Consequently these surface films can be regarded only as temporary expedients requiring frequent renewals where there is any traffic. In order for such film forming treatments to provide even a reasonable degree of permanence they must be highly abrasion resistant. A few films, usually of the synthetic resin types, add measurably to the abrasion resistance of the floor (Table XI), but these can be regarded as exceptions rather than the rule.

TABLE No. XI

Abrasion Resistance of Floor with Various Types of Finish

Type of Floor	Finish	Depth of Abrasion Inches
Uncolored Concrete	None	.015
" "	Magnesium fluosilicate	.012
" "	Oil Finish	.012
" "	Synthetic Resin Finish	.006
Colored Metallic Agg.	None	.0019
" " "	Resin—applied before curing	.0012
" " "	Resin—wax-applied before curing	.0016
" " "	Wax Emulsion—applied after curing	.009

The surface hardeners of the chemically reactive type are of no value on a good concrete floor. They can be regarded only as palliatives in cases where the floor was improperly designed, laid, or cured. To provide before the floor is laid for the use of a surface hardener is an admission of inability properly to install a concrete floor. While such a specification is logical when the architect has reason to doubt the capacity of the floor contractor he would do better to specify a dispersing agent, with or without metallic aggregate, for two reasons. First, a better floor will be secured at no greater or at less cost. Second, it puts the full responsibility on the cement floor contractor to use proper methods and produce a good floor finish. Occasionally when a floor contractor finds a specification which calls for an after treatment he is encouraged to take advantage of such a specification to slight the quality of his work because responsibility for the wearing qualities of the floor will probably be put on the after treatment instead of where it belongs.

In a few cases, especially for added resistance to corrosion, surface treatments of the film forming type may be of some value but can be regarded as only temporary.

COLORED CONCRETE FLOORS

Most concrete floors are designed primarily for utility and appearance is not an important factor. In some cases, as in offices, showrooms, schools and other institutional buildings, recreation rooms and other similar locations it is desirable to have the decorative effect of color. In certain industries color serves a practical purpose in showing up material spilled on the floor: this is true, for example, in powder plants.

It is, of course, possible to color concrete floors by painting or similar surface treatments. These are all generally unsatisfactory and at best are, like the surface treatments previously discussed, purely temporary. To produce a long-lived and satisfactory colored floor the color should be incorporated in the concrete itself. A surface coloring is simply a means of remedying a defect, either failure to provide color in the first instance or a means of restoring an improperly laid floor or one laid with unsuitable materials.

There are two general methods of producing a colored concrete floor. One is to incorporate color in the topping mortar mix. This method can be used only in two-course construction as the incorporation of color throughout the concrete of a monolithic floor would be prohibitive in cost. This means of securing color also suffers from the disadvantages of the danger of loose bond which always exists in two-course construction and also the added expense of this type of construction.

The other method consists in the application of a colored shake made up of pigment, aggregate and cement. This method has the advantages of much lower cost since the required amount of color, the most expensive ingredient, is much less. Further, it can be applied to monolithic floors which are less expensive to lay and present no danger of loose bond. It is, moreover, possible to secure better colors and finishing is made much easier. Finally, by selection of a suitable aggregate for the "shake", preferably metallic, a much more wear resistant surface can be produced. (Table XII).

TABLE No. XII

Color Throughout Top Finish vs. Colored Shake With Metallic Aggregate

Compressive Strength—Lbs. per sq. in.	3 days	7 days	28 days
Colored Top Finish (1:1½:1½ Mix)	3020	3980	5570
Colored Metallic Shake (1:2 Mix)	3465	6305	10250
Abrasion Resistance	Depth of Abrasion—Inches		
Colored Top Finish (1:1½:1½ Mix)	.0051		
Colored Metallic Shake*	.0019		

*A shake of 1 pt. cement to 2 pts. Colored Metallic Aggregate by weight on a 1:1½:1½ uncolored top finish at rate of 40 = metallic aggregate per 100 sq. ft.

Two objections have been raised to the "shake" method of coloring concrete floors. Both are matters of misunderstanding and without foundation in fact. First, the prejudice which has been raised by the old practice, previously discussed, of using neat cement shakes on wet floor mixes has caused some skepticism regarding the shake method. This is entirely without foundation in fact since on a floor laid properly at a dry

consistency and with a "shake" properly proportioned with respect to aggregate, cement, and pigment, the quality of the surface is improved rather than impaired.[8] Second, it is objected that with color in the surface layer only the floor will present an appearance on wearing which is not pleasing. This is not a valid objection because a properly laid floor with a suitable colored shake has adequate wear resistance so that the colored surface will not be worn through during the expected life of the floor. Further, if the colored surface of a floor is worn through—whether a "shake" finish or an integrally colored topping—the useful life of the floor is practically ended. When deterioration of a floor has progressed to a point where the top 1/16" is worn through in places the floor thereafter will continue to deteriorate so rapidly that replacement or repairs will be required in a very short time.

The conclusion seems inevitable that the most satisfactory and most economical means of securing a colored floor is incorporation of a pigmented shake in the surface of the concrete (Fig. XIX). It is, however, necessary to take certain precautions in coloring a concrete floor and these apply equally to a "shake" and color throughout the topping.

Fig. XIX

Maroon Concrete Floor in St. Mark's Episcopal Church, Buffalo, N. Y., laid with a shake of metallic aggregate, dispersing agent, and pigment.

First, the pigment used to produce the color must be suitable. It must be light-fast, alkali-fast (on account of the alkaline nature of the cement), of high tinting strength to avoid use of excess pigment, and of such a nature and degree of purity that it will have no injurious effect on the hydration reactions of the cement. These requirements limit the types

[8]Research Paper RP 1252 Journal of Research of the National Bureau of Standards, p. 564.

of pigments which may be used to the iron oxides and a few other inorganic pigments. Otherwise the problem is one of selection from among the available pigment oxides.

Second, addition of pigment to either a "shake" or a topping involves the addition of fines to the mix which implies in turn the necessity for additional water, lower strength, increased volume change, and greater porosity. For this reason a pigment of high tinting strength should be selected so that a minimum of pigment will be required to produce the desired color.

Consideration should also be given to the nature of the aggregate to be used in the shake. For the greatest serviceability there seems no question that a metallic aggregate should be used just as is the case with uncolored floors. The same requirements with respect to the quality of the metallic aggregate are essential. It has been urged that, on wearing, exposure of the metallic aggregate will detract from the appearance of the floor. A study of this subject reveals that, although exposure of the aggregate does detract from the appearance of the colored surface, it makes little difference whether the aggregate be metallic or non-metallic, even in the lighter colors. On the other hand, the wearing qualities of the metallic aggregate are greatly superior (Table No. XIII). Under certain conditions of exposure, such as exterior exposure without much traffic or in the presence of salt water, objectionable rusting of the metallic aggregate may occur. In such cases a silica aggregate of good quality is preferable.

TABLE No. XIII

Abrasion Resistance of Various Types of Aggregates

Type of Aggregate	Depth of Abrasion Inches
Metallic	.0046
Silica	.0081
Marble	.0084
Fused Alumina	.0106

The principle of dispersion is especially applicable to colored concrete floors since certain dispersing agents for cement will also act as dispersing agents for the pigment (Fig. XX). These actions have highly beneficial effects on the properties, including color, of the floor.

Dispersion of the cement in the shake (or in the topping) has the beneficial effects already discussed. These include lower water, increased workability, increased wear resistance, lower porosity, and decreased volume change. Due to the lower water requirement of dispersed cement it is possible to place colored floors with less water than would be required for a plain floor with undispersed cement (Fig. XXI). In this manner the disadvantages ordinarily entailed in the addition of pigment are overcome.

Dispersion of the pigment also contributes to improved quality. Pigments, like cement, are normally flocculated in water (Fig. XX). The coloring effect of pigment is dependent in part on the inherent character of the pigment but for a given pigment is a function of surface area. Therefore, dispersion of the pigment improves the coloring effect secured with a given quantity of the pigment so that less pigment is required for

Fig. XX

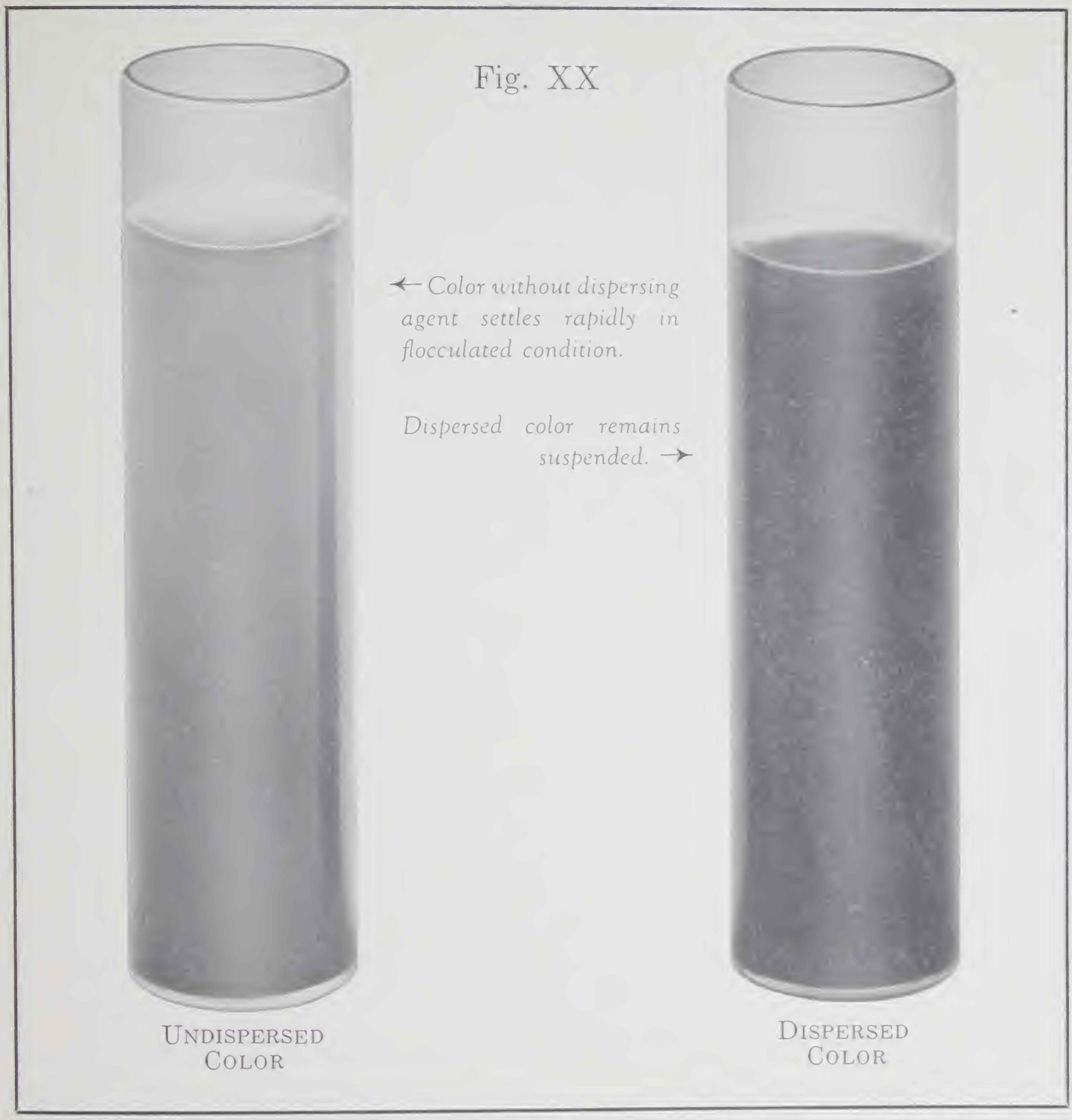


Fig. XXI

Topping Mortar with Dispersed and Undispersed Pigment

Topping Mortar with Undispersed Pigment | Plain Topping Mortar | Topping Mortar with Dispersed Pigment

the desired color and consequently less additional water need be used in the "shake" (or topping). The colors secured are also brighter. Dispersion of the pigment improves both the properties of the concrete floor and also its color.

Certain limitations of colored concrete floors should be recognized. Owing to the nature of cement mixes, the matte texture of concrete surfaces, and the limited selection of pigments which are suitable for use in concrete, bright or brilliant colors cannot be expected. The variety of colors is also limited. Since the color of a concrete surface will vary with a great many factors such as water content, temperature, working and trowelling, rate of drying and others which cannot practically be controlled within absolute limits, complete uniformity of color over the entire floor surface cannot be attained. With proper design of the floor and reasonable care during installation a very satisfactory appearance and permanent color can be secured. A suitable finish of either the wax or oil film type will add greatly to the appearance and serviceability of colored concrete floors.

Cement dispersion appears practically indispensable in producing colored concrete floors especially in view of the fact that the dispersing agent acts also on the pigment. In producing a colored concrete floor care is required in the selection of a suitable pigment and in following out, most carefully, good practice in laying, finishing, and curing the floor. The colored concrete floor can be most satisfactorily produced by incorporation in the surface of the floor of a color shake consisting of a suitable pigment, a good quality metallic aggregate, cement, and an appropriate cement dispersing agent. This method not only produces a floor having improved properties with respect to strength, volume change, porosity, durability, and wear resistance but also gives the best color. Finally, a floor so colored is also the most economical type of colored floor.

SUMMARY

The principles applicable to concrete generally are also applicable to concrete floors. These, however, present certain problems; notably need of a very high degree of wear resistance and low volume change at the surface.

A satisfactory solution to the problem of wear resistance is found in the incorporation of a layer of metallic (iron) aggregate in the surface but as an integral part of the floor. Such a metallic aggregate should be properly graded and free from impurities such as oil, grease, non-ferrous metal particles and alkalies.

Dispersion of the cement, with a suitable dispersing agent, is effective in improving the properties of concrete floors just as it improves the properties of concrete generally. By utilizing the cement with greater efficiency it makes possible greater economy in producing a floor of desired quality. Dispersion of the cement has special added advantages in the incorporation of metallic aggregate in the floor by improving workability, extending the time during which this operation may be satisfactorily carried out, and by reducing cracking, checking, and crazing. Metallic aggregates for concrete floors should be combined with a suitable cement dispersing agent.

Except in unusual circumstances metallic aggregate floors will be more satisfactory and more economical than plain concrete floors. In

those cases where concrete floors are to be laid without metallic aggregate design of the concrete and mortar mixes with a cement dispersing agent will give more satisfactory results and will effect economies.

Surface hardeners of the chemical type, which react with the lime of the cement, applied to the floor after it has hardened, have no value when the floor has been properly designed and installed. They are effective in improving, temporarily, defective floors. Film forming treatments may be of some benefit in improving resistance to corrosion but are only temporary, requiring frequent renewal.

Colored concrete floors are most satisfactorily produced by incorporation in the surface of a "shake" consisting of pigment, metallic aggregate, cement, and a dispersing agent. The pigment must be carefully selected and of highest quality. Obviously the metallic aggregate should be properly graded and treated and the "shake" should be properly proportioned. Under types of exposure which are conducive to rusting it is preferable to use a silica aggregate. The dispersing agent greatly improves the properties of the floor because it acts not only on the cement but also on the pigment.

Whatever the type of floor involved cement dispersion should be applied. Thereby the properties of the floor will be improved and the cost of the floor reduced by more effective utilization of the cement.

APPENDIX I — SPARK HAZARDS

Ordinarily it is not considered that a concrete floor presents any fire hazard. The floor itself is fire resistant and any tendency to sparking is negligible. In certain cases, however, such as airplane hangers, powder plants, and similar conditions, static or mechanical sparks may assume considerable importance. Whenever an industry presents a fire hazard from combustible gases or dusts, such as the milling industry, or the warehousing of volatile inflammable liquids such as gasoline, avoidance of sparks from any source including the floor is of vital importance.

Where static charges are built up on equipment on the floor the danger of sparks from this source may be avoided if the floor itself is reasonably conductive so that the charge will be disseminated through the floor. This is especially applicable to airplane hangers and landing aprons.

Hobnailed shoes and other metal articles tend to strike sparks on a concrete floor. Such mechanical sparks may constitute a fire hazard although there is no agreement among fire preventive experts whether they do or not.

As far as static dissemination is concerned a concrete floor is a very poor conductor of electricity when dry. It is a fair conductor when wet but it must be assumed that the floor or even an exterior pavement may be dry when the hazardous condition occurs. The conductivity of a concrete floor is greatly increased by providing it with a metallic aggregate surface as illustrated by data in Table No. XIV. From these determinations it is apparent that with less than 60 # metallic aggregate per 100 sq. ft. of floor the metallic particles are not in sufficiently close contact, that is, they are more or less separated by cement, to give high conductivity. With over 60 # per 100 sq. ft. the metallic aggregate gives a floor of fairly high conductivity so that ready dissemination of static may be expected.

TABLE No. XIV

Conductivity of Concrete Floors

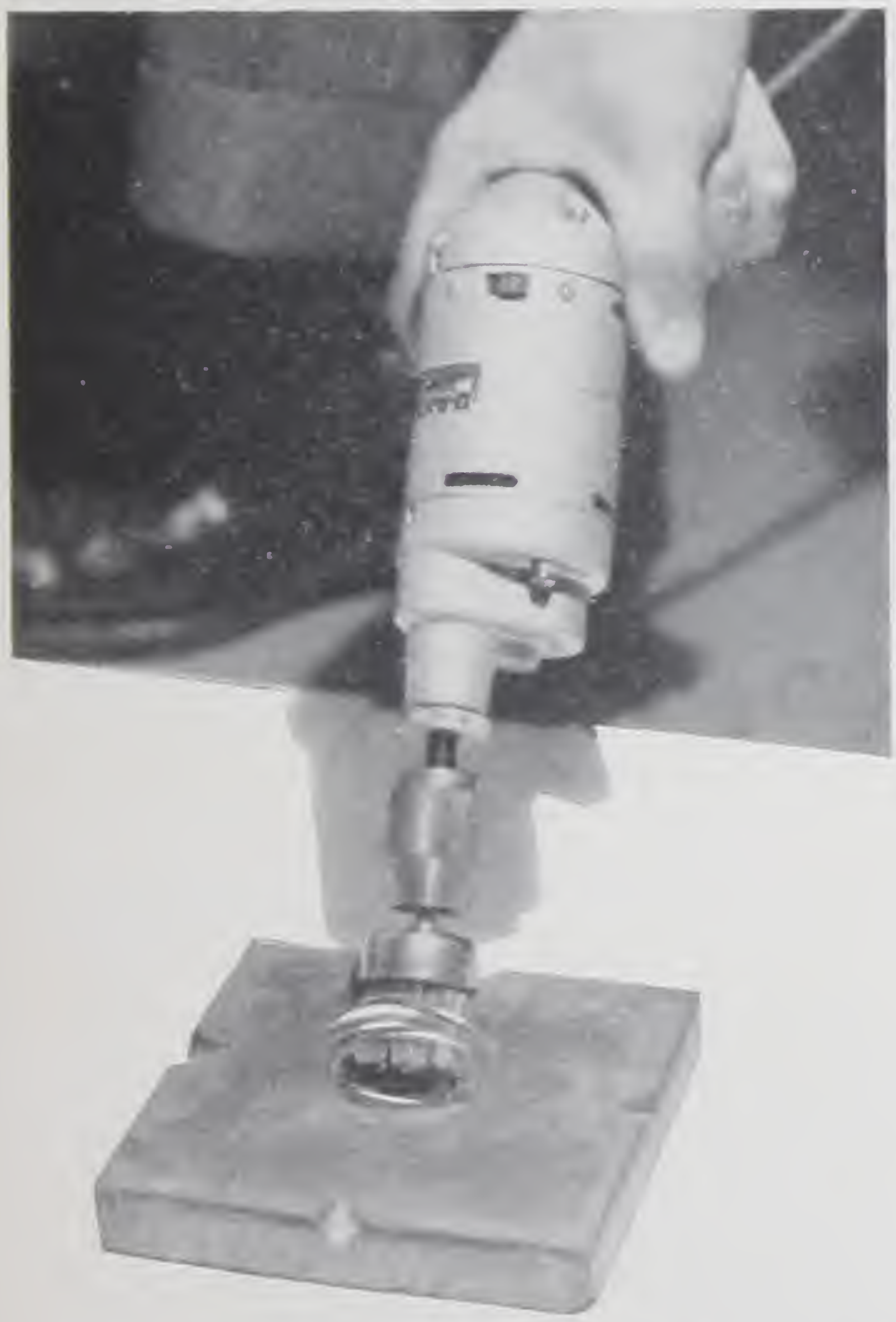
Metallic Aggregate	Conductivity-Micro-Amps./in.
None	2.2
30 # per 100 sq. ft.	5.3
60 # per 100 sq. ft.	49.5
90 # per 100 sq. ft.	91.1
120 # per 100 sq. ft.	122.1

It has frequently been thought that a metallic surface floor would increase the danger of mechanical sparks. Quite the contrary is the case. Mechanical sparks are produced by striking together a metallic and a non-metallic article as, for example, the flint and steel used before matches were developed. Therefore a non-metallic floor, including a plain concrete floor, presents a considerable spark hazard from hob-nailed shoes, tools and other metallic articles. On the contrary a floor with a metallic surface, such as a concrete floor with a metallic aggregate shake, eliminates such spark hazard (Fig. XXII). For this purpose not less than 60 # metallic aggregate per 100 sq. ft. should be used, applied properly in two separate shakes. Care in laying the floor should be taken in order to exclude any non-metallic particles such as sand from the surface either brought up from the concrete underneath or carried on to the fresh surface from adjacent areas. It should be pointed out that the tendency

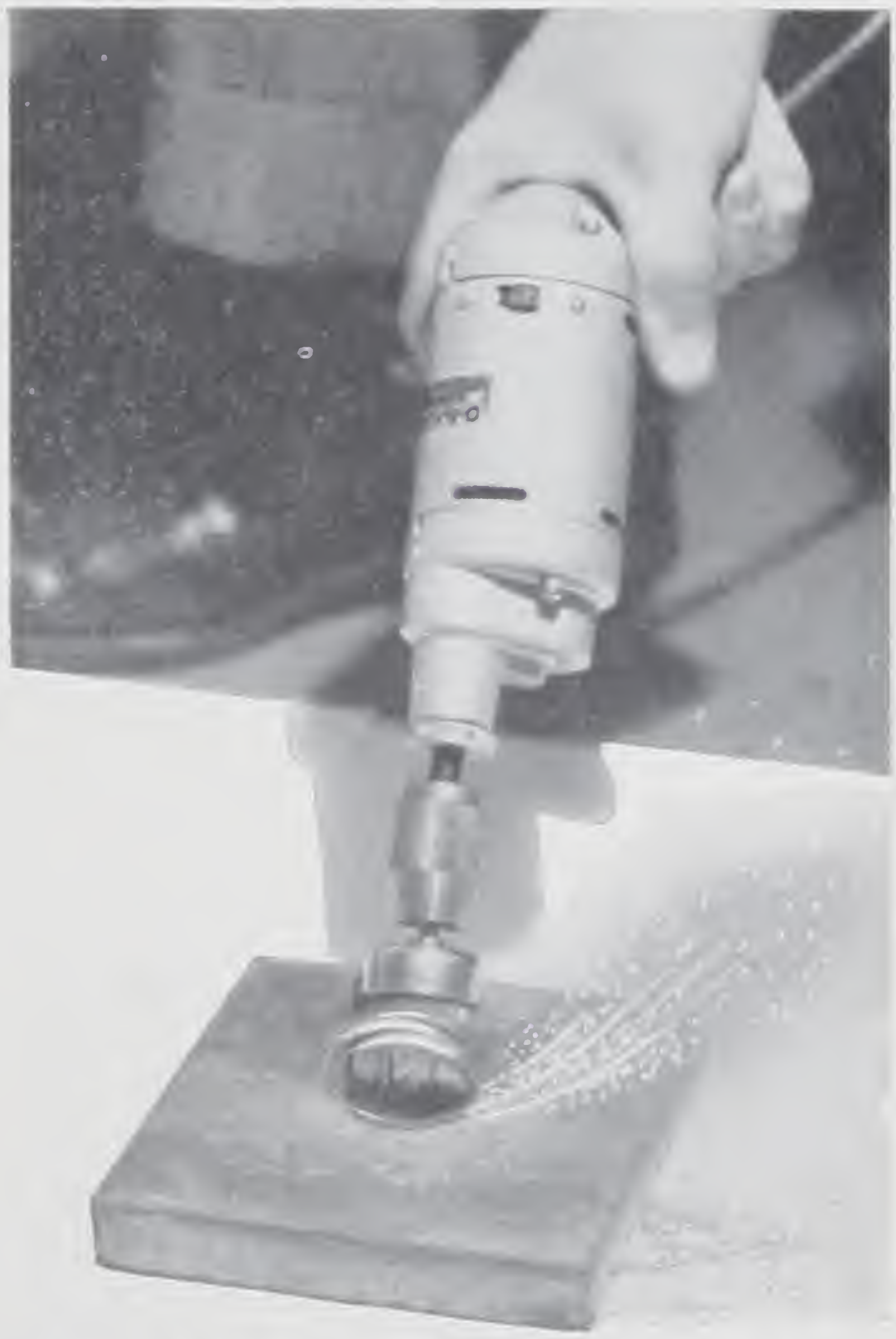
toward mechanical sparking is increased rather than decreased by the use of metallic aggregate when the floor will be struck by stone or other non-metallic substance. In most locations, however, the danger from striking with metallic objects would seem to be much greater than from striking with non-metallic objects.

Fig. XXII

Mechanical Sparking on Non-metallic and Metallic Concrete Floor Surfaces



Friction test with rapidly rotating steel brush on metallic floor surface.



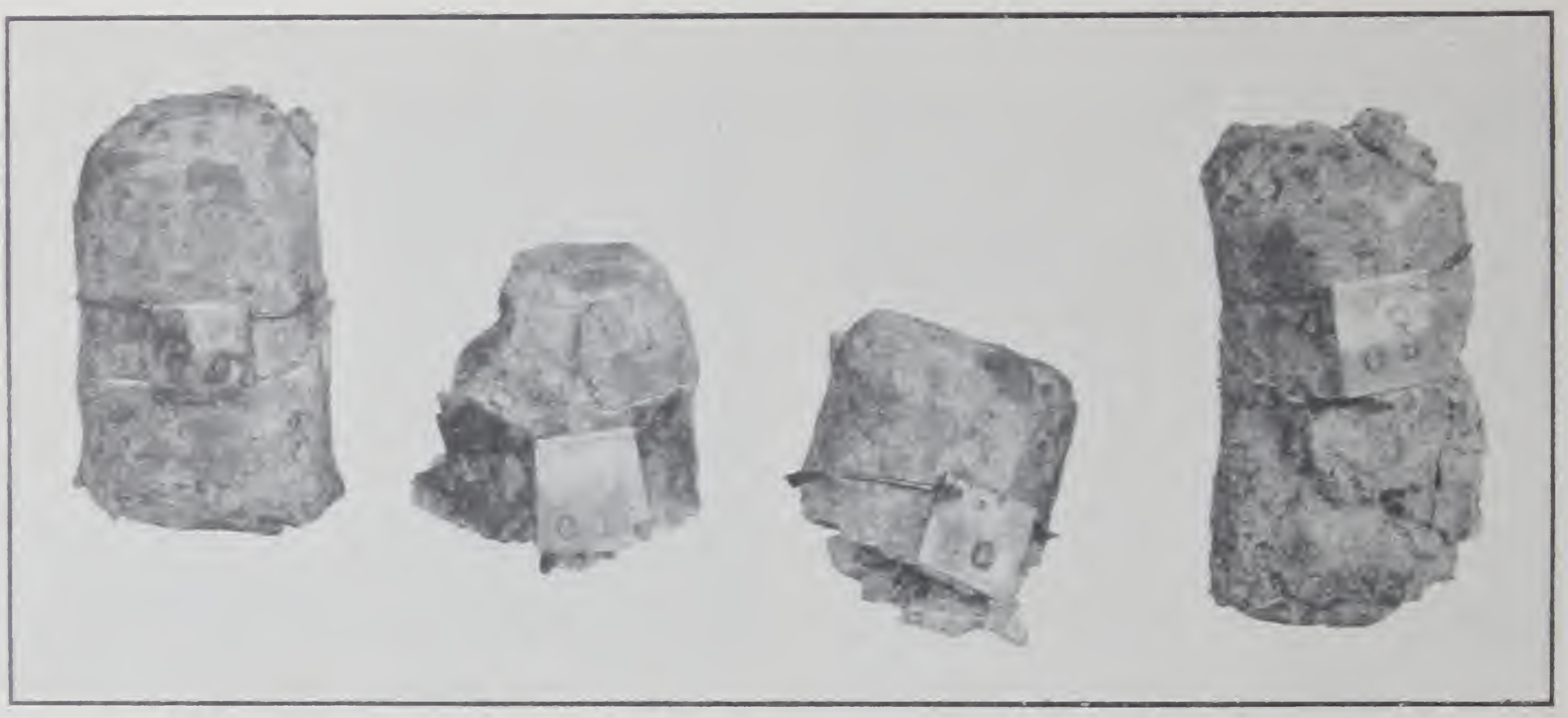
Same friction test applied to concrete surface without metallic aggregate.

The greater freedom from inequalities and the lower porosity of metallic aggregate surface floors make them much easier to clean. This in itself reduces fire hazards where combustible materials are involved as well as improving sanitary conditions in other cases.

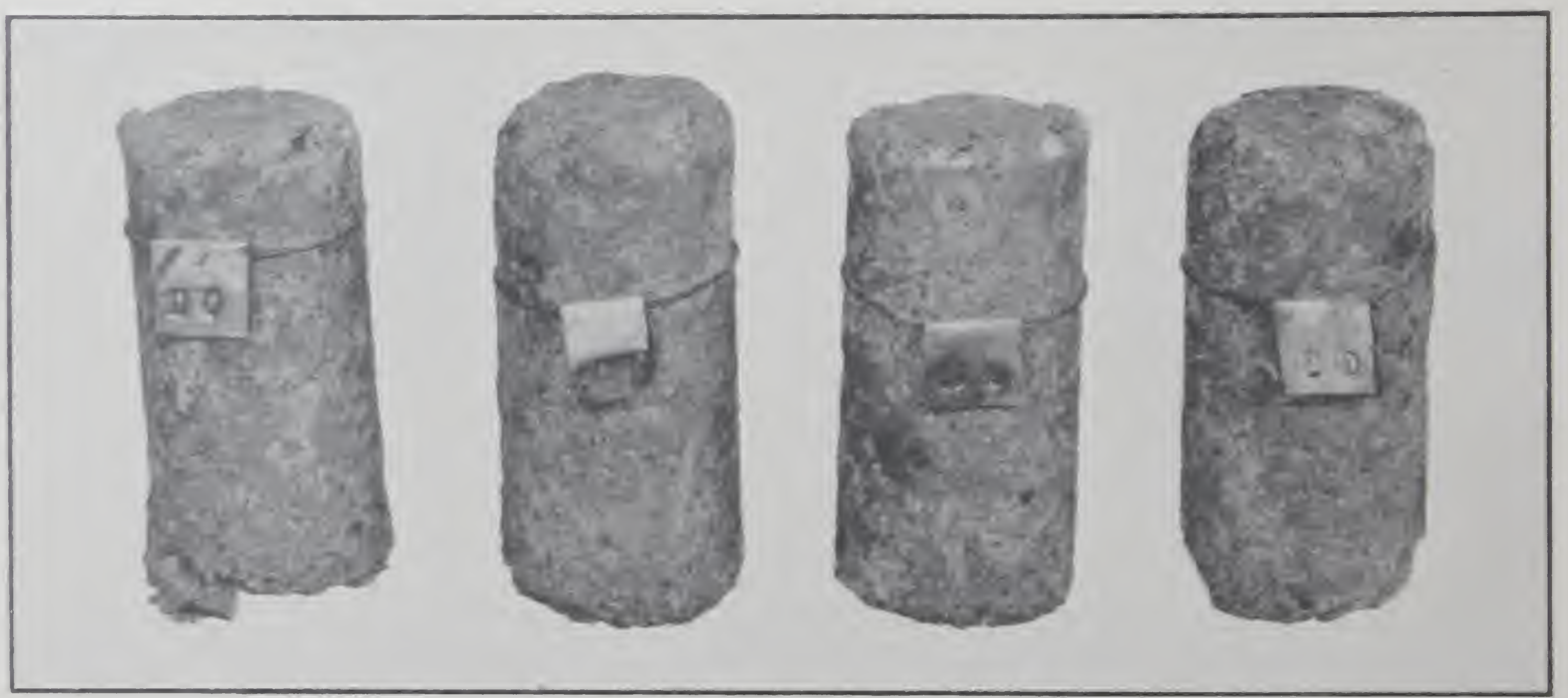
APPENDIX II — SPECIAL CORROSIVE CONDITIONS

The corrosion resistance of concrete mixes is greatly enhanced by dispersion of the cement (Fig. XXIII—cf. also Fig. XVII). The incorporation of metallic aggregate in the surface of the floor also adds to resistance to this type of attack (cf. Fig. VII). It may then be concluded that a floor laid using a cement dispersing agent will be more resistant to corrosion and this effect will be further enhanced where a suitable metallic aggregate is used.

Fig. XXIII



UNDISPERSED CEMENT - 2 YEARS IN 8% MAGNESIUM SULPHATE



DISPERSED CEMENT - CONCRETE OF SAME DESIGN AND CONSISTENCY
2 YEARS IN 8% MAGNESIUM SULPHATE

Since, however, portland cement itself is very readily attacked by certain corrosive agents and is quite readily soluble in moderately strong acids it cannot be expected that cement dispersion and metallic aggregate will make a concrete floor acceptable for certain conditions of corrosive service. Under any alkaline condition a concrete floor can be made satisfactory. Under any strong acid conditions, a concrete floor is not to be recommended: some other type of floor such as brick or vitrified tile should be used.

The greatest difficulty with respect to a decision regarding the use of a concrete floor arises for those intermediate conditions where a concrete floor of high quality might not prove serviceable. A practical rule in this respect would appear to be that under acid conditions, including conditions where acid is produced by the decomposition of organic matter, a portland cement floor should not be used unless evidence is available to show that such a floor would withstand the particular conditions involved.

Unfortunately the possible conditions which might be encountered in industry are so varied that it is a practical impossibility to make actual tests which cover all the possibilities. Concrete floors are certainly not to be recommended when exposed to mineral acids. Acid sulphate salts, such as aluminum sulphate, also have a very deleterious effect. With the weak organic acids it is sometimes possible to produce concrete floors which will give good service but this depends on the conditions in each case. Neutral sulphates attack concrete but it may be protected against them. Alkaline solutions, unless very strong, are not usually injurious and neutral salts which are not sulphates have little effect.

The experimental results of investigations carried out to determine the corrosion resistance of metallic aggregate floors under a few special conditions are given in Table No. XV. It would appear that abrasion resistance is not adversely affected to any appreciable extent by exposure of cement floors with metallic aggregate to picric acid or ammonium nitrate. Cutting oils, especially those containing sulphur, do have some adverse effect but this is not serious as the abrasion resistance remains about equal to the value at the end of the original curing period (the slabs exposed to the air and not to cutting oil have increased in abrasion resistance due to additional curing). Under these three conditions portland cement floors with metallic aggregate may be expected to give satisfactory service.

TABLE No. XV

Corrosion Resistance of Metallic Aggregate Floors (with dispersing agent)

I. Picric Acid

Lbs. Metallic Aggregate per 100 sq. ft.	Depth of Abrasion—Inches: Unexposed	Depth of Abrasion—Inches: Exposed 1 month to picric acid
60	.0062	.0070
120	.0066	.0070

II. Ammonium Nitrate

Lbs. Metallic Aggregate per 100 sq. ft.	Depth of Abrasion—Inches: Unexposed	Depth of Abrasion—Inches: Exposed 3 weeks to saturated Ammonium Nitrate Solution
None	.017	.069
60	.005	.008

III. Cutting Oils

Metallic Aggregate 60 # /100 sq. ft.

Time of Exposure	Depth of Abrasion—Inches: Exposed to Oil	Depth of Abrasion—Inches: Exposed in Air
1 Month	.0049	.0043
2½ Months	.0069	.0013
6 Months	.0042	.0023

APPENDIX III — METHODS OF CURING

While the curing of concrete is in no way related to cement dispersion this subject is of such importance that it seems desirable to treat it here briefly.

Other things being equal, the quality of any concrete depends on adequate curing. This is true of floors and is of special significance in this relation because the results of inadequate curing become apparent much more rapidly in the case of floors than with most other concrete and because such very disastrous consequences are produced.

To cure concrete, including floors, it is necessary that the concrete be kept substantially saturated with water and at a moderate temperature for a reasonable length of time. The lower the temperature the longer is the time required for curing. Curing below 50 deg. F. is so slow as to be impractical for floors.

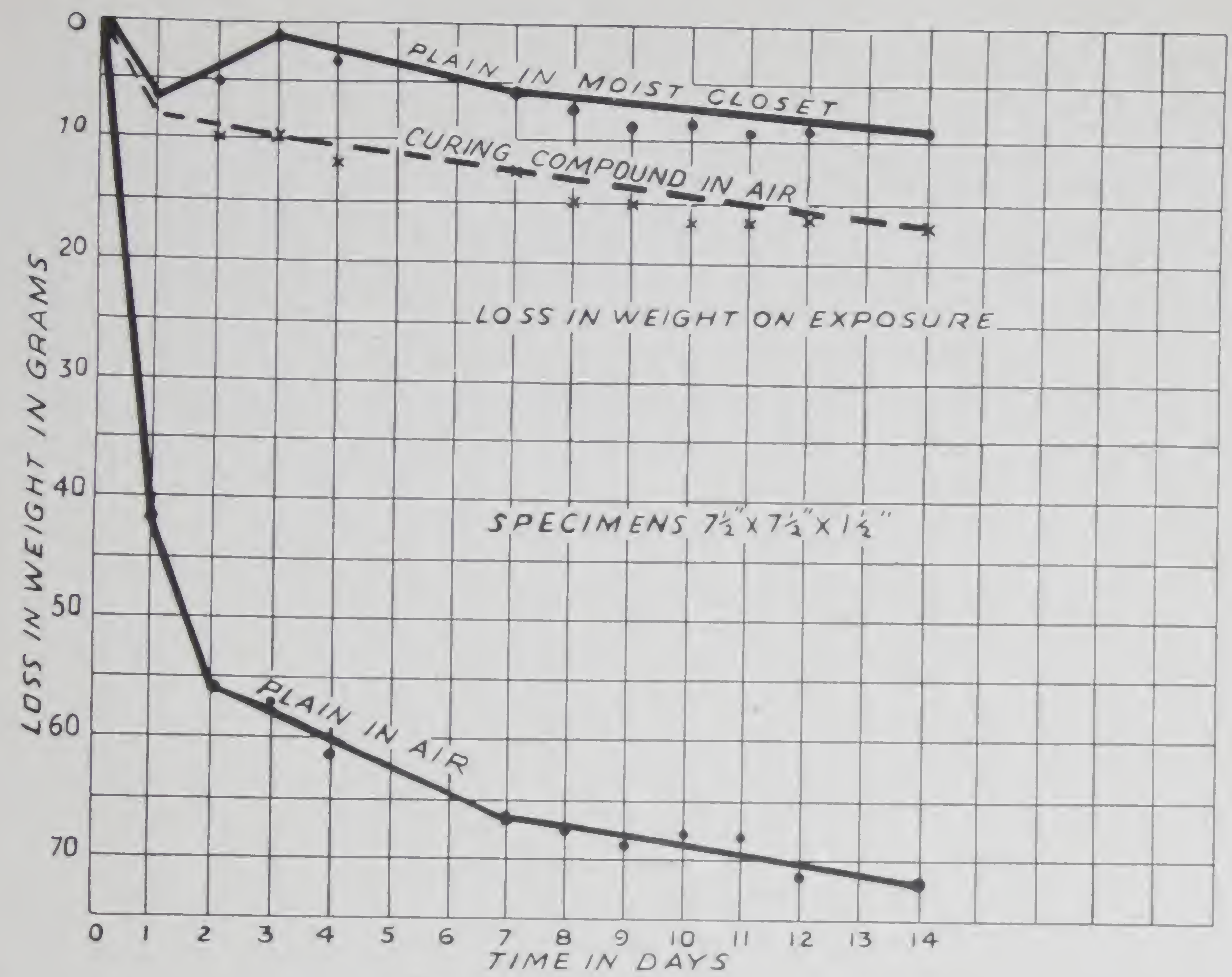
In order to maintain an adequate temperature in cold weather the floor mix itself should be placed at a reasonable temperature but heating of the mix is not very effective because the large surface area compared with the volume of a floor permits the mix to cool rapidly, probably before the finishing operations are completed. The floor should be enclosed and not exposed to the weather. When the outside temperature is below 50 deg. F. artificial heat should be provided for the duration of the curing period. There are numerous methods of providing heat including salamanders. These are not to be recommended when placed on the floor surface as they give very uneven heat causing drying out in some areas and inadequate heat in others. They also give off fumes which may react deleteriously with the cement at the surface. Accelerators and high early strength cement will shorten the curing period and are helpful in cold weather but it is doubtful whether they are desirable at normal temperatures or above.

To maintain water in contact with the cement in the floor numerous means may be employed. These include ponding, sprinkling, and covering with sand, burlap, straw, waterproof-paper or a membrane curing compound. Any method which keeps the moisture in the floor is satisfactory.

Ponding is certainly an ideal method of curing on horizontal surfaces but is not usually applicable to most floors. It has the further disadvantage that the floor cannot be used during the curing period. Sprinkling and covering with sand, burlap, straw, etc., which should be wet down at intervals are satisfactory if properly carried out, but without constant inspection there is always some question whether the floors are kept adequately wet. Waterproof-paper, lapped and sealed, is very satisfactory if it is not torn during the curing period or if tears are promptly repaired.

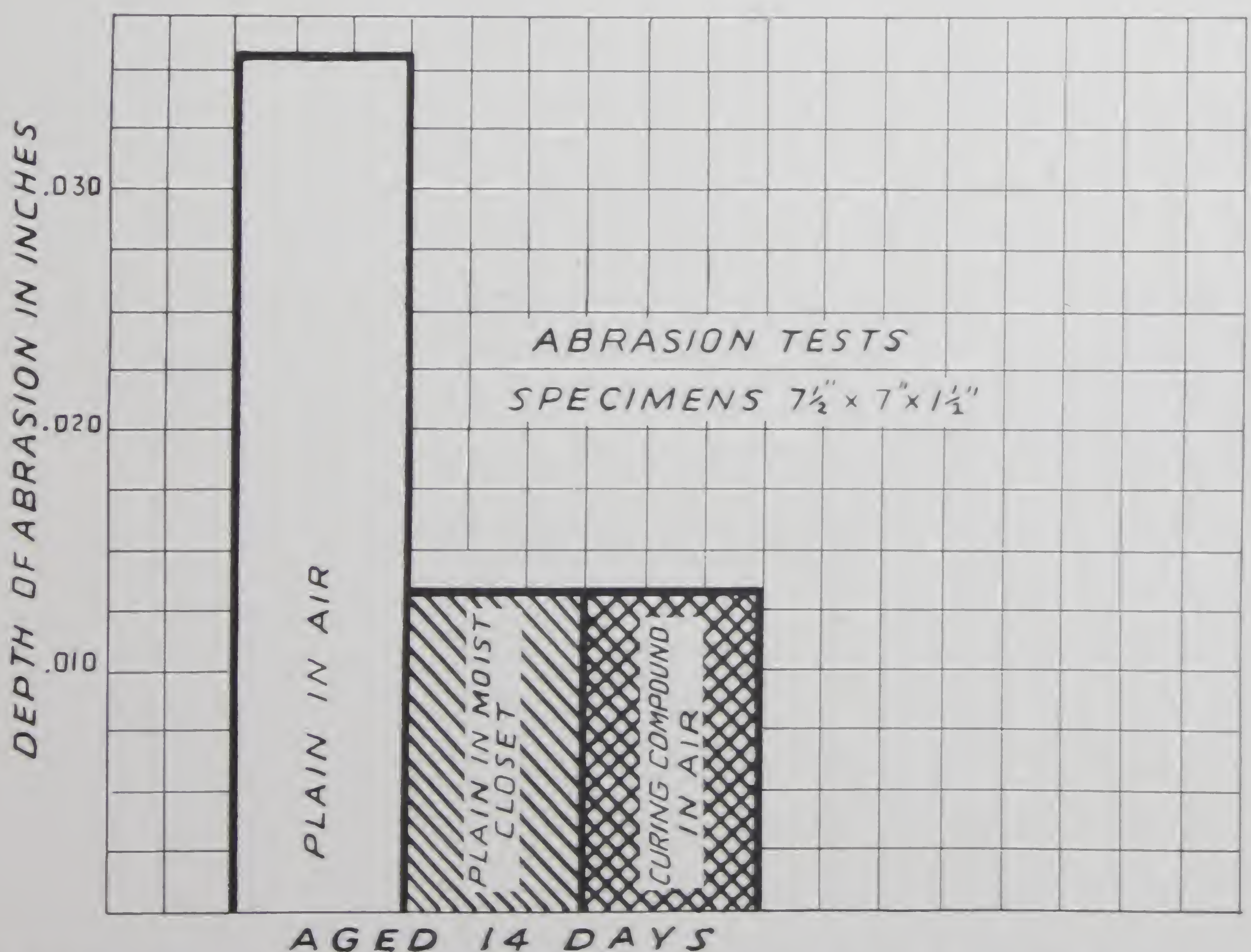
Curing with a transparent membrane is probably the most satisfactory method for floors. The curing efficiency is very high for a good quality curing compound (Fig. XXIV) and the abrasion resistance secured by this method approximates that of moist closet or perfect curing (Fig. XXV). A further advantage of good membrane curing is that the surface film on the floor does not dust as it does with other methods of curing. Economically membrane curing is less expensive than curing with paper and probably less expensive than most other methods of curing when the labor involved in carrying them out properly is taken into consideration.

Fig. XXIV



This chart shows the loss in moisture for untreated specimens in the moist closet, representing perfect curing, compared with losses for similar specimens allowed to dry out in the air, representing no curing at all. The curve for the specimens treated with the curing compound shows that losses in moisture are only slightly greater than those for perfect curing and represent only an insignificant part of the total water in the mix. Much more than enough water for complete hydration of the cement is retained in the mix.

Fig. XXV



In this chart are given the results of tests to determine abrasion resistance. The untreated specimens which were allowed to dry out without curing show little resistance compared with those given perfect curing in the moist closet. The specimens treated with the curing compound and exposed to the air show resistance equal to that of the perfectly cured specimens.

For curing colored floors only two methods are at all satisfactory. These are curing with waterproof paper and membrane curing. The other methods tend to stain the floor, to produce uneven colors, and to cause efflorescence. They do not protect the floor from dirt and stains during the construction period. Of the two relatively satisfactory methods, membrane curing is preferable. Besides giving excellent curing it prevents the deposition of efflorescence on the colored surface, provides even drying out, and protects the floor during the construction period. It is practically impossible to cover a floor with paper so that the paper is in contact with the floor at all points. Consequently uneven drying and differences in color, and the formation of some efflorescence may be expected with this method.

APPENDIX IV —
SURFACE FINISHES FOR COLORED CONCRETE FLOORS

On account of the limitations of colored cement floors it is practically essential to provide some type of finish. This should serve the primary purposes of minimizing the inherent defects of the colored floor and of providing a durable surface finish which will enhance both the color and the wearing qualities of the floor.

There are several types of finish which may be used and these may be considered from two points of view. From the point of view of composition, there is the film-forming or oil type of finish and the wax type. Of course, there may be a hybrid which combines some of the properties of both. From the point of view of operation there is the type of finish which is applied to the completed floor after it has hardened and dried out and that which is applied during some prior stage and assists in the subsequent development of the floor.

The requirements of an oil type finish are that it will adhere to the floor, that it will be durable under the alkaline and moist conditions under which it may have to exist and that it will have reasonable wearing qualities. A number of compositions based on various synthetic resins fulfill these conditions more or less satisfactorily. The advantages of this kind of finish are that it gives a high gloss, resists wear fairly well if of good quality (cf. Table XI), is fairly easily removable, is easy to apply and is not slippery. Its disadvantages are that its application is limited to a dry surface, it will wear out fairly rapidly and then complete reapplication is necessary, and it enhances rather than covers defects. It is not possible to add color to such a finish to cover defects and inequalities in the floor. If sufficient opaque pigment is added to produce any real result, this type of finish becomes a paint and is subject to the well-known defects of paints on concrete surfaces. It is true that a dye-stuff, transparent, may be added to impart some color but this has no real utility. In a thin film such a transparent coloring matter has a very small effect on the appearance and, just as such materials are not usable in the floor mix itself due to lack of permanence, such a color fades rapidly in the light so that in a few days all color effect has been lost.

The requirements of a wax type finish are that it will adhere to the floor and that it will be durable and wear resistant. A number of compositions based on waxes of high melting point fulfill these conditions. Usually a wax in the form of an emulsion is more satisfactory than in solution. The advantages of this type of finish are that it is applicable to a wet or dry surface, it gives a fairly high gloss, it is easily renewable in part or in whole, it gives excellent wear resistance (cf. Table XI) and it minimizes the defects in the floor surface. It is possible to add to the wax an opaque pigment which will enhance the color of the floor and will tend to even up differences in color due to defects in conditions or workmanship. Its disadvantages are that it is slippery, that it tends to turn white with exterior exposure, and that, if sufficiently hard to give good wearing qualities, it may present some difficulties in application.

In the foregoing discussion, the two types have been considered purely from the point of view of application to the finished floor. It is perfectly possible to so formulate either type, by using suitable vehicles, that it can be applied to the floor surface after it has set but before it has hardened or cured to any substantial extent. Application of the finish at this time

has certain advantages. If it forms a relatively impermeable coating, as it should, it assists in curing, does away with the necessity of using curing paper and eliminates the variations in color due to differences in curing conditions. It prevents discoloration of the surface by efflorescence since it prevents movement of water to carry soluble salts to the surface. It protects the floor from staining by plaster, dirt, paint, and other foreign substances during the time between laying the floor and completion of the structure. If of the wax type it enhances the color of the floor and increases the uniformity of color by minimizing defects. The relative merits of the oil and wax types are the same in this method of application as they are for similar finishes applied to completed floors.

The floor finish applied as a curing coat would appear to be the ideal. It suffers from one defect, the necessity for application at the right time under proper conditions. To be effective the finish must be applied before any of the defects which it will prevent, such as efflorescence, have developed. On the other hand it must not be applied before the floor has taken a set as this will prevent proper hardening of the cement at the surface. Since one purpose of the finish is to assist curing by retaining the moisture in the floor it must be applied to a saturated surface; otherwise it will keep moisture out of a dried surface resulting in a weak cement surface and also a weak finish as the binder will have been drawn out of the finish by the unsaturated floor surface. Finally, it is necessary to apply the finish with reasonable care to avoid streaking, overlapping, and other variations in the color of the finish itself. The color of the finish should approximate to a reasonable degree that of the floor surface so that with wear too great a contrast will not develop.

APPENDIX V — NON-SLIP FLOORS

In most areas cement floors do not present a problem with respect to slipperiness as such floors even when smooth are not inherently very slippery. In certain instances, however, this factor may be of some importance. This may be the case on inclined areas such as ramps, stair-treads, and factory areas subject to oil and grease.

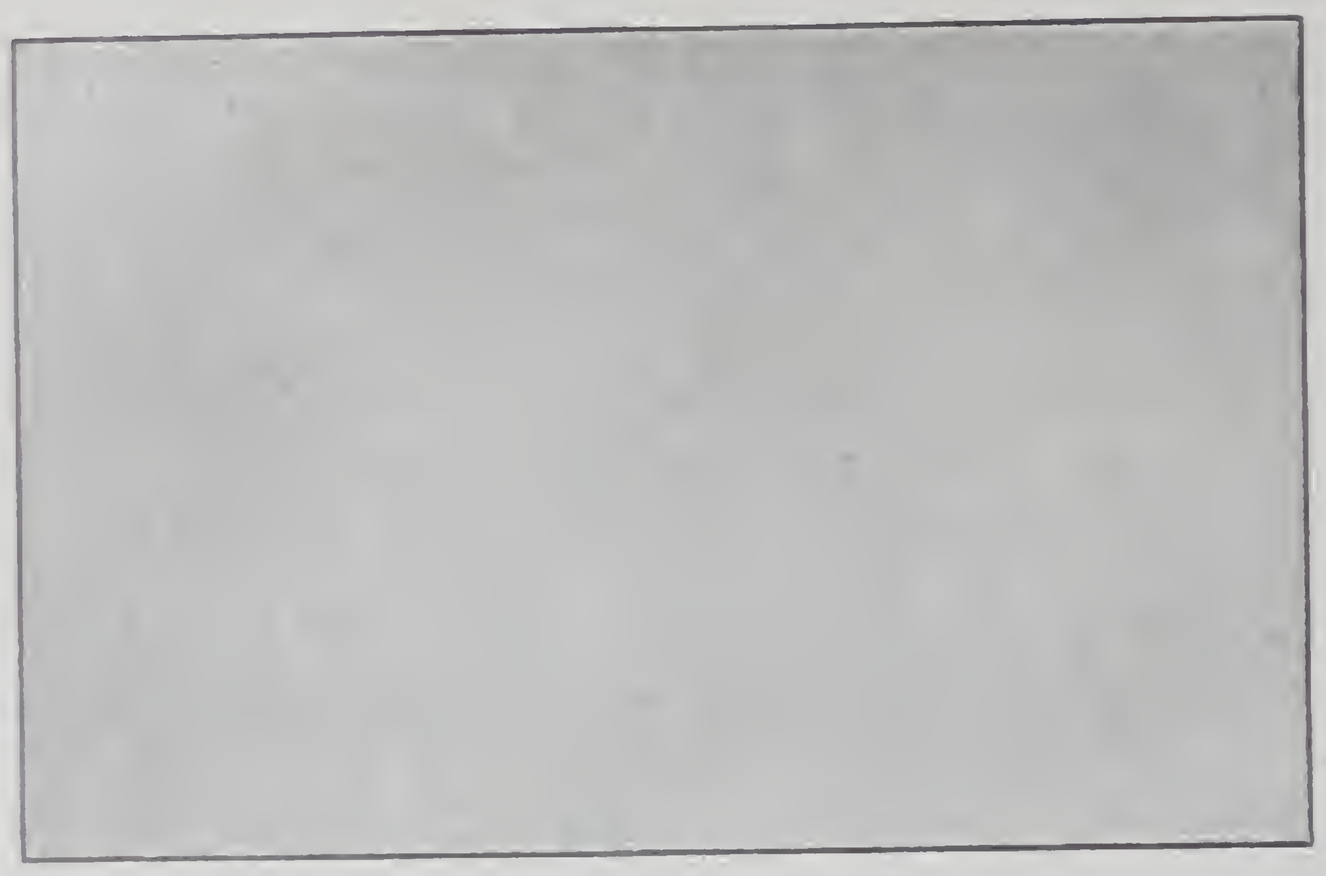
The property which most influences the slipperiness of a floor is its smoothness. Unfortunately this is also the property which to a large extent affects the resistance of the floor to wear. As has been pointed out, wear on a cement floor is due in large part to the effects of impact in breaking down the cement paste, in dislodging aggregate particles from the cement matrix, and in shattering brittle aggregate. In so far as the surface of the floor is free from inequalities these effects of traffic will be minimized, but these same inequalities are the means of reducing the tendency of one surface to slide over another, i.e., of preventing slipperiness. The conclusion seems to be that to reduce slipperiness it is necessary to increase roughness, by one means or another, but that in so doing wear resistance will be decreased to some extent.

One means of producing a non-slip cement floor surface, which has been proposed, is to introduce into the surface an exceptionally hard aggregate. For this purpose fused or sintered aluminum oxide (alundum) or silicon carbide (carborundum) have been used. It is alleged that the mechanism whereby these materials produce their effect is that the softer portions of the floor surface, the cement and softer aggregate, wear more rapidly under traffic leaving the particles of harder aggregate projecting slightly and thereby producing a roughened surface. It is difficult to demonstrate experimentally that this is so because when the floor is just finished, before it has been subject to traffic, this roughness has not developed and the floor is no more and no less slippery with the hard aggregate. In order to develop the non-slip qualities it is necessary that a certain amount of wear of a certain kind shall have been applied to the surface and it is difficult to duplicate this condition artificially. Experience would indicate, however, that non-slip qualities do develop but quantitative data on this point are meager if they exist at all.

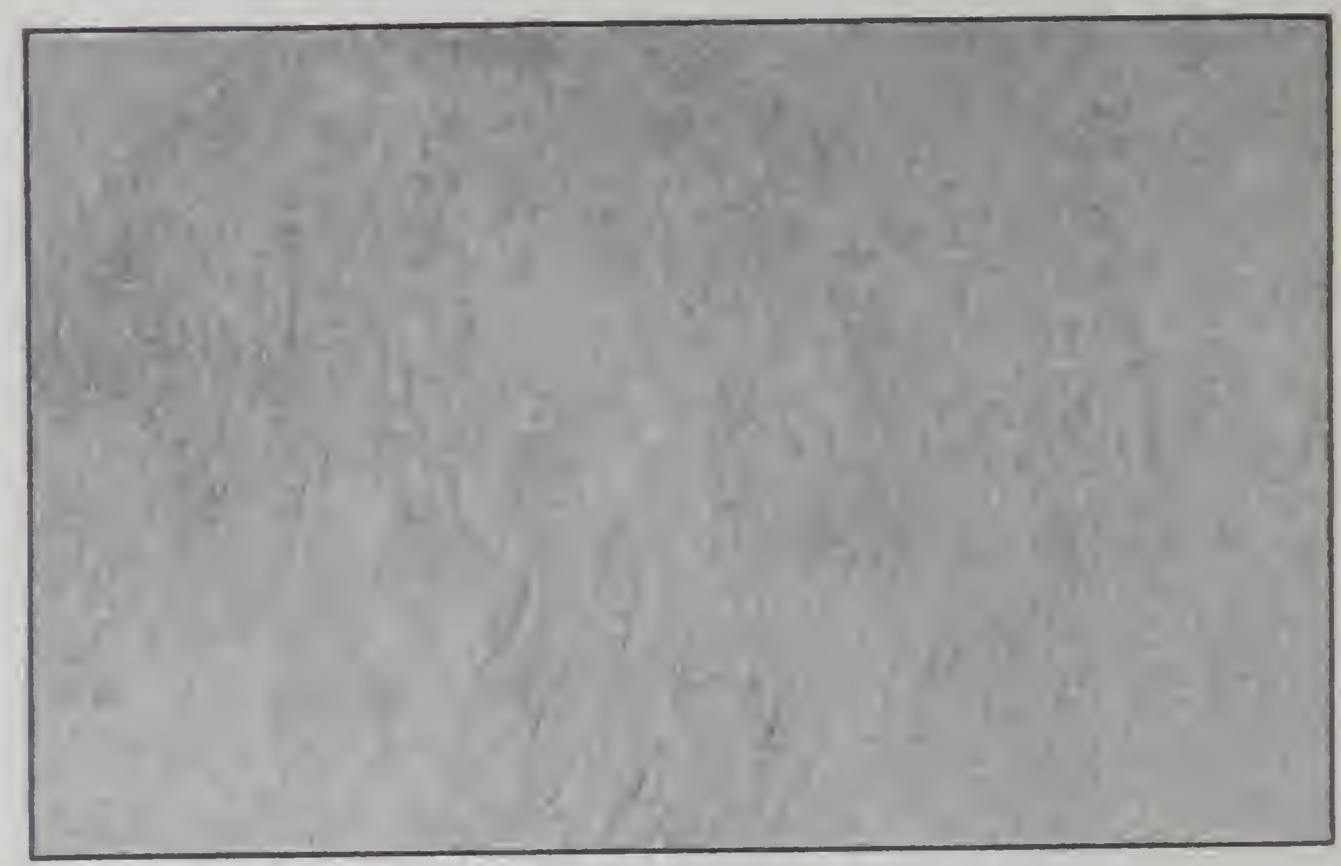
It is also urged that the wearing qualities of the concrete floor are improved by the use of these exceptionally hard aggregates but this may be questioned. The greater the differences in hardness between the components of the floor the more rapid will be the development of inequalities which aggravate the effects of traffic. On this basis it would seem that the harder aggregates would tend to accelerate wear. (cf. Table No. XIII). Moreover, hard but brittle aggregates will shatter readily and will be as easily dislodged from the cement matrix as softer aggregates.

What appears to be a more practical method of producing non-slip qualities through a rougher surface is to be found in the method of finishing the floor. This is similar to the "brooming" frequently used in finishing concrete highways to give non-skid surfaces. The cement floor may be given a rough surface by leaving it with a float finish, by flat trowelling only, or by roughening after smooth trowelling. The last method seems to have something to recommend it in that the advantages of the normal finishing methods, in compacting the surface and eliminating initial shrinkage, are secured as well as that of a non-slip surface.

Fig. XXVI



Metallic Aggregate Floor with Smooth Trowel Finish.



Metallic Aggregate Floor with Non-slip Finish—(Mechanical Float used after Trowelling).

A method of producing a rough non-slip surface is to place and finish the floor in the usual manner by floating and trowelling twice. Immediately after the last trowelling but before the floor has hardened so that it cannot be worked, ridges are brought up on the surface by going over it with a float, or with a trowel held flat, or with a mechanical float. In the hand method a circular motion is used for the last operation. By these means circular ridges are brought up on the surface which give excellent non-slip qualities and which will wear well.

A great improvement in the wearing qualities of this type of non-slip finish is secured by incorporating metallic aggregate in the surface of the floor. The floor is laid and floated in the usual manner. The metallic aggregate shake is dusted over the surface, floated in, and trowelled. After a second trowelling the mechanical float is run over the floor. This brings up circular ridges which make the floor non-slip even when subject to oil and the metallic aggregate contained in these ridges (Fig. XXVI) imparts a very high degree of wear resistance, so that the ridges do not wear off quickly, as occurs with concrete surfaces without metallic aggregate finished in this manner.

Master Builders Research Laboratories
Cleveland, Ohio

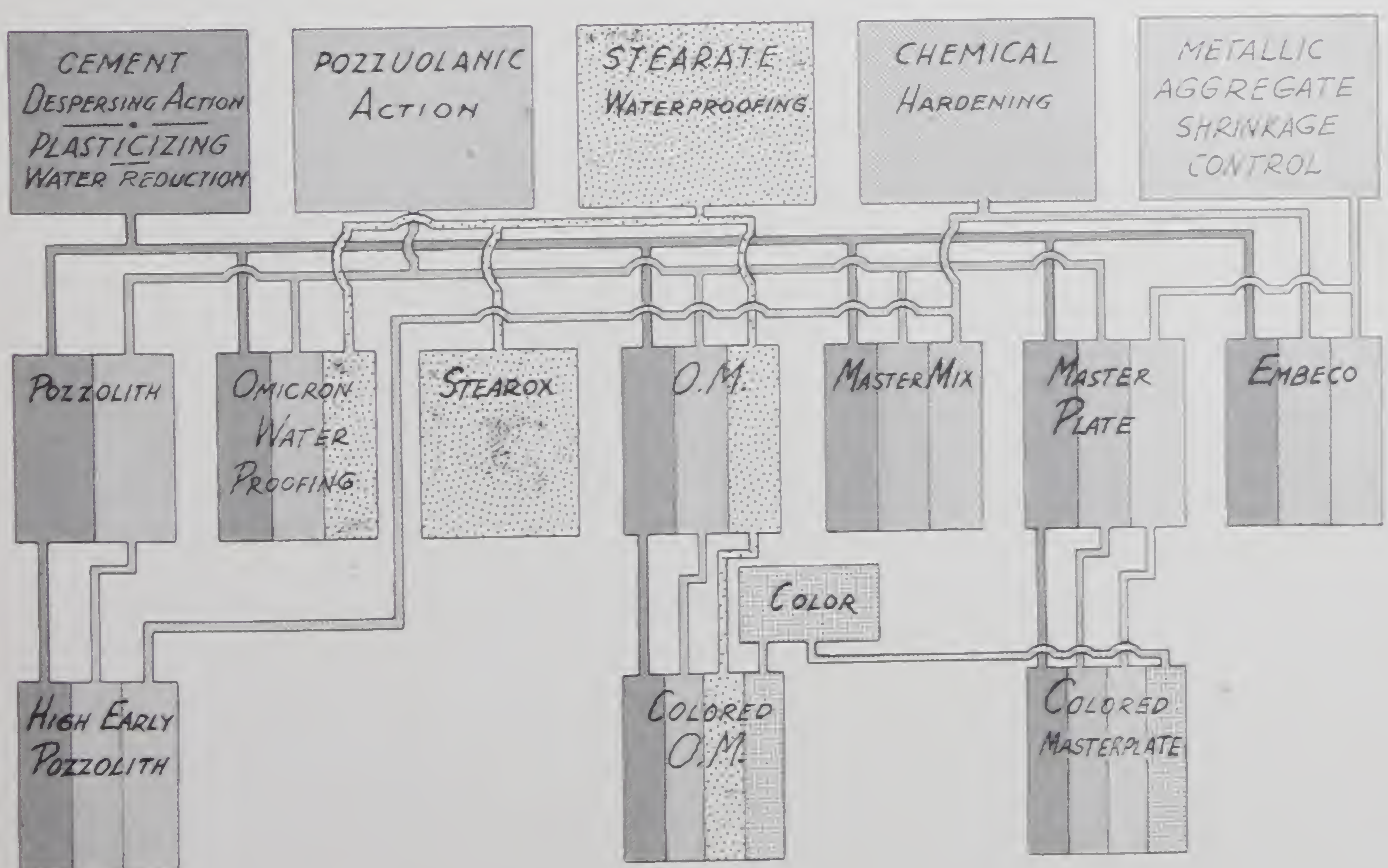
MASTER BUILDERS PRODUCTS EMPLOYING THE CEMENT DISPERSION PRINCIPLE

The principle of dispersion of cement is applicable to any type of work involving cement in mortar or concrete. This work is of a very varied nature and for different applications somewhat different properties are required. To accomplish these purposes most economically the cement dispersing agent may be combined with other basic principles for the improvement of specific properties of concrete and mortar, as illustrated by the diagram below. These include pozzuolanic activity, stearate waterproofing, chemical hardening, and metallic aggregates.

The Master Builders Company has developed a group of products adapted to various specific concrete and mortar applications. The exclusive dispersing agent is incorporated in each of these products in a manner to impart the maximum effect on the resultant structure at minimum cost. These products are as follows:

Application	*Product*
Concrete (General)	Pozzolith
High Early Strength Concrete	High Early Pozzolith
Concrete (Exposed to Capillary Moisture)	Omicron Waterproofing
Floors — Heavy Duty	Masterplate
Floors — Light Duty	Master Mix
Colored Floors	Colored Masterplate
Brick Mortar	Omicron Mortarproofing ("O. M.")
Colored Brick Mortar	Colored Omicron Mortarproofing
Grouting and Maintenance	Embeco

PRODUCT COMPOSITION DIAGRAM



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